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Alternation in the Atomic Weights of the Elements

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EVER since the first formulation of the periodic system of the elements on the basis of their atomic weights, there have been many attempts to represent the relationship between the atomic weights of different elements by some algebraic function or other type of formula from which the atomic weights of all the known elements might be calculated. In early literature, almost all of the formulas proposed involved some arbitrary integer assigned to the element.[1–10] It was Harkins and Wilson[11] who first represented in 1915 the atomic weights as a "linear" function of atomic number and pointed out the phenomenon of the alternation in the atomic weights. They grouped the elements into two series: the even-numbered, or "helium system," elements; and the odd-numbered, or "helium-hydrogen system," elements. They represented the atomic weight W by an equation with an alternation term that disappears when the atomic number Z is even and is effective when it is odd, as follows:

$$W=2(Z+n)+[\tfrac{1}{2}+\tfrac{1}{2}(-1)^{Z-1}],$$

where n is an integer that is zero for elements with atomic numbers below 27. This equation is similar to the definition of isotopic number, $A=2Z+I$, if we compare W with the mass number A and the term $2n+[\frac{1}{2}+\frac{1}{2}(-1)^{Z-1}]$ with the isotopic number I. It seems, however, that they did not fully recognize the true generality of the alternation of the atomic weights and overlooked the inversion of the sign of the alternation after atomic number 31, which fact cannot be represented by the simple even-odd alternate equation such as they proposed.

It is to be pointed out that the alternation in the atomic weights and in the mass numbers of the main isotopes of the elements is a very general and remarkable phenomenon which should not be overlooked in any attempt to formulate an exact expression for atomic weight. It seems to be of fundamental importance in connection with any discussion or correlation of relationships between atomic weight and any other atomic property.

The alternation in the atomic weights can be best exhibited by comparing the value of any atomic weight with the average value of those of

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[7] Minet, *Comptes rendus* **144**, 8 (1907).
[8] Delauney, *Comptes rendus* **145**, 25 (1907); **106**, 1405 (1888); **109**, 526 (1889).
[9] Egerton, *J. Chem. Soc.* (London) **95**, 238 (1909).
[10] Warrington, *Chem. News* **111**, 110 (1915); *Chem. Abstracts* **9**, 1413 (1915).
[11] Harkins and Wilson, *J. Am. Chem. Soc.* **37**, 1383 (1915).

TABLE I. Data for the elements and their main isotopes.*

Atomic number Z	Symbol	Atomic weight W	$\frac{W_{Z+1}+W_{Z-1}}{2}$	Mass number A	$\frac{A_{Z+1}+A_{Z-1}}{2}$	A_Z-A_{Z-1}	No. of neutrons N	$\frac{N_{Z+1}+N_{Z-1}}{2}$	N_Z-N_{Z-1}	Isotopic number I
1	H	1.0080		1			0			
2	He	4.003	3.97	4	4	3	2	2	2	0
3	Li	6.940	6.51	7	6.5	3	4	3.5	2	1
4	Be	9.02	8.88	9	9	2	5	5	1	1
5	B	10.82	10.52	11	10.5	2	6	5.5	1	1
6	C	12.010	12.41	12	12.5	1	6	6.5	0	0
7	N	14.008	14.005	14	14	2	7	7	1	0
8	O	16.0000	16.5	16	16.5	2	8	8.5	1	0
9	F	19.00	18.09	19	18	3	10	9	2	0
10	Ne	20.183	21.00	20	21	1	10	11	0	1
11	Na	22.997	22.25	23	22	3	12	11	2	0
12	Mg	24.32	24.98	24	25	1	12	13	0	1
13	Al	26.97	26.19	27	26	3	14	13	2	0
14	Si	28.06	28.98	28	29	1	14	15	0	1
15	P	30.98	30.06	31	30	3	16	15	2	0
16	S	32.06	33.22	32	33	1	16	17	0	1
17	Cl	35.457	36.00	35	36	3	18	19	2	0
18	A	39.944	37.28	40	37	5	22	19	4	1
19	K	39.096	40.01	39	40	−1	20	21	−2	4
20	Ca	40.08	42.10	40	42	1	20	22	0	1
21	Sc	45.10	43.99	45	44	5	24	23	4	0
22	Ti	47.90	48.03	48	48	3	26	26	2	3
23	V	50.95	49.96	51	50	3	28	27	2	4
24	Cr	52.01	52.94	52	53	1	28	29	0	5
25	Mn	54.93	53.93	55	54	3	30	29	2	4
26	Fe	55.85	56.94	56	57	1	30	31	0	5
27	Co	58.94	57.27	59	57	3	32	30	2	4
28	Ni	58.69	61.26	58	61	−1	30	33	−2	5
29	Cu	63.57	62.04	63	61	5	34	32	4	2
30	Zn	65.38	66.65	64	66	1	34	36	0	5
31	Ga	69.72	68.99	69	69	5	38	38	4	4
32	Ge	72.60	72.32	74	72	5	42	40	4	7
33	As	74.91	75.78	75	77	1	42	44	0	10
34	Se	78.95	77.41	80	77	5	46	43	4	9
35	Br	79.916	81.33	79	82	−1	44	47	−2	12
36	Kr	83.7	82.70	84	82	5	48	46	4	9
37	Rb	85.48	85.67	85	86	1	48	49	0	12
38	Sr	87.63	87.20	88	87	3	50	49	2	11
39	Y	88.92	89.43	89	89	1	50	50	0	12
40	Zr	91.22	90.92	90	91	1	50	51	0	11
41	Cb	92.91	93.59	93	94	3	52	53	2	10
42	Mo	95.95		98		5	56		4	11
43	Ma		98.83		100			57		14
44	Ru	101.7		102			58			14
45	Rh	102.91	104.2	103	103	1	58	58	0	13
46	Pd	106.7	105.4	104	105	1	58	59	0	12
47	Ag	107.880	109.56	107	109	3	60	62	2	13
48	Cd	112.41	111.32	114	111	7	66	63	6	18
49	In	114.76	115.56	115	117	1	66	68	0	17
50	Sn	118.70	118.26	120	118	5	70	68	4	20
51	Sb	121.76	123.16	121	124	1	70	73	0	19
52	Te	127.61	124.34	128	124	7	76	72	6	24
53	I	126.92	129.46	127	130	−1	74	77	−2	21
54	Xe	131.3	129.92	132	130	5	78	76	4	24
55	Cs	132.91	134.33	133	135	1	78	80	0	23
56	Ba	137.36	135.92	138	136	5	82	80	4	26
57	La	138.92	138.75	139	139	1	82	82	0	25
58	Ce	140.13	139.92	140	140	1	82	82	0	24
59	Pr	140.92	142.20	141	141	1	82	82	0	23
60	Nd	144.27	143.46	142	143.5	1	82	83.5	0	22
61	Il*	146?	147.35	146	147?	4	85	86	3	24
62	Sm	150.43	149.0	152	149.5	6	90	87.5	5	28
63	Eu	152.0	155.67	153	154	1	90	92	0	27
64	Gd	156.9	155.6	158	156	5	94	92	4	30
65	Tb	159.2	159.68	159	161	1	94	96	0	29
66	Dy	162.46	162.07	164	162	5	98	96	4	32
67	Ho	164.94	164.83	165	165	1	98	98	0	31
68	Er	167.2	167.17	166	167	1	98	99	0	30
69	Tm	169.4	170.12	169	170	3	100	101	2	31
70	Yb	173.04	172.20	174	172	5	104	102	4	34
71	Lu	174.99	175.82	175	177	1	104	106	0	33
72	Hf	178.6	177.94	180	178	5	108	106	4	36
73	Ta	180.88	181.26	181	182	1	108	109	0	35
74	W	183.92	183.60	184	184	3	110	110	2	36
75	Re	186.31	187.06	187	188	3	112	113	2	37
76	Os	190.2	189.71	192	190	5	116	114	4	40
77	Ir	193.1	192.73	193	193.5	1	116	116.5	0	39
78	Pt	195.23	195.15	195	195	2	*117	117	1	39
79	Au	197.2	197.92	197	197.5	2	118	119.5	1	39
80	Hg	200.61	200.80	202	201	5	122	121	4	42
81	Tl	204.39	203.91	205	205	3	124	124	2	43
82	Pb	207.21	206.70	208	207	3	126	125	2	44
83	Bi	209.00	208.61	209		1	126		0	43
84	Po	210	215.0?							
85	Ab*	221?	216.0?							
86	Rn	222	222.5?							
87	Vr*	224?	224.03							
88	Ra	226.05	225.5?							
89	Ac*	227?	229.09							
90	Th	232.12	229.0?	232			142			52
91	Pa	231	235.10	231	235	−1	140	144	−2	49
92	U	238.07		238		7	146		6	54

* The atomic weights, main isotopes, and the number and range of the isotopes in Tables I, II and III are taken from *Handbook of chemistry and physics* (Chemical Rubber Publishing Co., ed. 26, 1942).

its nearest neighbors and indicating the sign of the difference by an arrow which points to the larger number, as shown in Table I. The alternate directions of these arrows and the inversion of the sign of the alternation after the element Ga ($Z=31$) is demonstrated by the observation that before Ga the odd-numbered element and after Ga the even-numbered element possesses higher atomic weight than the average of those of its nearest neighbors. It is obvious that the alternation in the atomic weights throughout the whole series of elements is so remarkable that any linear or nonalternate formula seems to be inherently not in accordance with fact.

It is of interest to note that, although the ill-ordered atomic weights of A and K are exceptions to the alternation rule, the atomic weights of Co and Ni and those of Te and I still follow the regular alternation. Another interesting point is that the atomic weights of the rare earth elements also follow this alternation rule with only one exception. Thus, the group number, or number of valence electrons, seems to have little to do with the phenomenon of the alternation of the atomic weights, as is to be expected from the fact that the atomic weight of an element depends essentially on the structure of its nucleus and not on the valence electrons.

The mass number A of the main isotopes of elements are also given in Table I. The alternation in this series exhibits the same feature as does the series of atomic weights. In this case the alternation also can be shown by comparing the differences in the mass numbers of two consecutive elements. As shown in Table I, in the case of most of the lighter elements ($Z<31$), the increase in mass number from an even-numbered element to an odd-numbered one is three times that from an odd-numbered to an even-numbered one. For the heavier elements, however, the increase from an odd- to an even-numbered element is for the most part five times that from an even- to an odd-numbered one. Thus we have not only the striking feature of alternation but also some simple numerical relations for the alternation.

The significance of the alternation can be best shown by tabulating the numbers of neutrons $N[=A-Z]$ in the nuclei of the main isotopes. From the table we see that, as the number of protons increases one by one, the number of neutrons may increase by zero, two or four—that is, by even numbers of units with exceptions in the cases of elements Be, N, Il and Pt. The tendency for the number of neutrons to remain unchanged in going from an element of odd Z to one of even Z before Ga, and from an element of even Z to one of odd Z after Ga, is outstanding when we glance at the table. The combination of these two tendencies makes the mass numbers of neighboring elements more nearly the same in going from an odd- to an even-numbered element before Ga, and in going from an even- to an odd-numbered element after Ga. This is the cause of the alternation in the mass numbers of the main isotopes. Now, the atomic weight of the natural mixed element is approximately equal to the mass number of the most abundant isotopes. Therefore, if we have any explanation for the alternation between an increase and no change in the number of neutrons of the main isotopes when Z increases, we explain the alternation in the atomic weights immediately. To account for the former it is necessary to apply the theories of nuclear stability.

In nuclear physics there are two main principles governing the structure of nuclei:[12] (i) the overwhelming strength of the neutron-proton interaction which, for small atomic weights, makes those nuclei most stable that contain as many neutrons as protons, and (ii) the "even-odd rule," to the effect that nuclei are most stable if they contain even numbers of neutrons and protons. The second rule is based on the Pauli principle and also probably on the nature of the attractive forces between like particles. With these principles we can easily see why the number of neutrons does not increase smoothly with increasing Z, but stepwise by even numbers of units with every other element. Although in the heavier nuclei the increasingly important Coulomb repulsion makes the stable nuclei contain fewer protons than neutrons, the alternation is still maintained. Thus the alternation is a natural consequence of the tendency of nuclei to acquire complete stability. The even-numbered elements, which, by the even-odd rule, are more stable and thus more abundant than the odd-numbered ones, attain the complete stability in

[12] Bethe and Bacher, *Rev. Mod. Physics* 8, 82 (1936), Secs. 6, 10 and 32.

TABLE II. Relative abundance of the lighter and heavier isotopes of elements of even atomic number.

Z	Symbol	No. of known isotopes	Range of isotopes	Middle point of range	Total % of lighter isotopes	Total % of heavier isotopes
2	He	2	3– 4			100?
4	Be	1	9			
6	C	2	12– 13		98.9	1.1
8	O	3	16– 18	17	99.8	0.2
10	Ne	3	20– 22	21	90.1	9.8
12	Mg	3	24– 26	25	83.2	16.8
14	Si	3	28– 30	29	92.7	7.3
16	S	4	32– 36	34(33)	97.8(95.3)	2.1(4.6)
18	A	3	36– 40	38(37)	0.3(0.3)	99.6(99.6)
20	Ca	6	40– 48	44(42)	98.7(97.2)	1.2(2.8)
22	Ti	5	46– 50	48	52.4	47.6
24	Cr	4	50– 54	52	92.9	7.0
26	Fe	4	54– 58	56	51.8	48.2
28	Ni	5	58– 64	61	95.2	4.7
30	Zn	5	64– 70	67(66)	80.2(64.5)	19.8(35.5)
32	Ge	5	70– 76	73(72)	52.5(34.8)	45.5(65.2)
34	Se	6	74– 82	78(77)	30.7(14.5)	69.3(85.5)
36	Kr	6	78– 86	82	8.1	91.9
38	Sr	4	84– 88	86(87)	5.5(13.9)	94.5(86.1)
40	Zr	5	90– 96	93(91)	81.5(53.8)	18.5(46.2)
42	Mo	7	82–100	96	48.9	51.1
44	Ru	7	96–104	100	21.0?	76.0
46	Pd	6	102–110	106(105)	45.6(21.4)	53.9(78.5)
48	Cd	8	106–116	111	21.7	78.3
50	Sn	10	112–124	118	38.1	61.9
52	Te	8	120–130	125(124)	12.1(6.8)	81.9(93.2)
54	Xe	9	124–136	130	32.0	68.0
56	Ba	7	130–138	134(136)	1.4(13.1)	98.6(86.9)
58	Ce	4	136–142	139(140)	2.0(45.0)	98 (55.0)
60	Nd	7	142–150	146	78.9	21.1
62	Sm	7	144–154	149	41.5	58.5
64	Gd	7	152–160	156	33.7	66.3
66	Dy	6	158–164	161(162)	12.4(35.5)	87.6(64.5)
68	Er	6	162–170	166(167)	19.8(49.3)	80.2(50.7)
70	Yb	7	168–176	172	23.6	76.4
72	Hf	7	172–180	176	2.9	97.1
74	W	5	180–186	183	31.5	68.5
76	Os	7	184–192	188	9.9	90.1
78	Pt	5	192–198	195	48.6	51.4
80	Hg	7	196–204	200	38.8	61.2
82	Pb	4	204–208	206	13.3	86.7
92	U	3	234–238	236	0.7	99.3

one of two ways; before Ga it is accomplished by lagging, that is, by maintaining unchanged, the number of neutrons; after Ga by advancing, that is, by increasing the number of neutrons. We may call the former an *even-lagging alternation* and the latter an *even-advancing alternation*.

The inversion of the sign of the alternation appears after the element Ga ($Z=31$). Before this element, an odd-numbered element has a higher atomic weight than the average of those of its nearest neighbors. This is the even-lagging alternation and is in accordance with the equation of Harkins and Wilson; that is, the isotopic number I actually is represented by a function of the form $2n+[\frac{1}{2}+\frac{1}{2}(-1)^{Z-1}]$, where $n=0$ for $1<Z\leqq 20$ and $n=2$ for $20<Z\leqq 30$, with only a few exceptions. On the other hand, after this element, the inversion of the sign of the alternation makes the atomic weights of an even-numbered element higher than the average of those of its nearest neighboring odd-numbered ones. Consequently, in the case of the even-advancing alternation, the equation of Harkins and Wilson loses its significance. It seems likely, therefore, that the rule of evenness and oddness is not as simple as the one proposed by them.

From the table we see that the appearance of this inversion is caused by the increase in the excess of number of neutrons over protons after the element Ga. The reason for this progressive increase after the element Ga may be the following. Experimentally, the nuclei that have the highest packing fractions, that is, the maximum binding energies, are those for which Z is about 30. From the point of view of "shell structure" the nucleus with 34 neutrons is just a completion of a closed shell ($4f$ shell).[12] Thus both experiment and theory indicate that the nuclear configuration of the element Zn with $Z=30$ and $N=34$ leads to a special stability. As soon as the nuclei get heavier, the Coulomb repulsion between the protons begins to be appreciable. In order to reduce considerably the Coulomb energy, which is proportional to Z^2A^{-1}, and thus to reduce the total energy of the nucleus, there must be a rapid increase in the number of neutrons immediately after a nuclear configuration having a special stability. Preceding this stable configuration, the number of neutrons tends to refrain from increasing and, as a consequence, the Coulomb energy becomes more appreciable. This explains

TABLE III. Relative abundance of the lighter and heavier isotopes of elements of odd atomic number.

Z	Symbol	No. of known isotopes	Range of isotopes	Middle point of range	Total % of lighter isotopes	Total % of heavier isotopes
1	H	3	1– 3	2	99.9	0.1
3	Li	2	6– 7		7.9	92.1
5	B	2	10– 11		18.4	81.6
7	N	2	14– 15		99.6	0.4
17	Cl	2	35– 37	36	75.4	24.6
19	K	3	39– 41	40	93.3	6.7
27	Co	2	57– 59	58	0.2	99.8
29	Cu	2	63– 65	64	68.0	32.0
31	Ga	2	69– 71	70	61.2	38.8
35	Br	2	79– 81	80	50.6	49.4
37	Rb	2	85– 87	86	72.3	27.7
45	Rh	2	101–103	102	0.1	99.9
47	Ag	2	107–109	108	52.3	47.5
49	In	2	113–115	114	4.5	95.5
51	Sb	2	121–123	122	56	44
61	Il	2	151–153	152	49.1	50.9
71	Lu	2	175–176	—	97.5	2.5
75	Re	2	185–187	186	38.2	61.8
77	Ir	2	191–193	192	38.5	61.5
81	Te	2	203–205	204	29.1	70.9

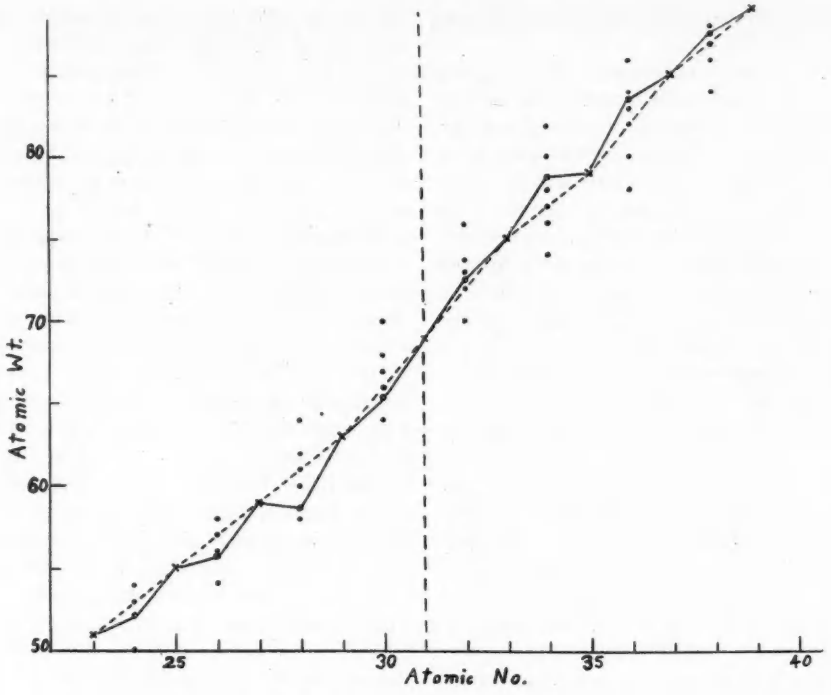

FIG. 1. The inversion of the alternation in atomic weights. The solid curve represents an even-lagging alternation in the left-hand part of the figure ($Z<31$) and an even-advancing alternation in the right-hand part ($Z>31$).

why, immediately after the element with $Z=30$, the number of neutrons is increased twice successively by four and then alternately by four, instead of by two as before Ga.

The preceding consideration leads us to assume that: (i) as the atomic number increases, the heavier isotopes of an element tend to be more stable and thus more abundant and (ii) the inversion of the alternation is merely a transition from the lighter elements, in which lighter isotopes predominate, to the heavier elements, in which heavier isotopes predominate.

The validity of these assumptions can be tested by calculating the relative abundance of the lighter and the heavier isotopes of the elements. To do this, all the known isotopes of each element are divided at the middle point of the range of the mass numbers of its isotopes. For example, there are ten known isotopes of Sn, ranging from mass numbers 112 to 124. The middle point of the range is 118, which is the mass number of an isotope of known relative abundance 22.5 percent. Dividing this by two and adding it to the sum of the relative abundance in percentage of heavier mass numbers and to that of the lighter mass numbers, one gets 61.9 and 38.1 percent, respectively, for the relative abundances above and below the middle point of the range. The results are given in Table II. It is evident that for almost all the lighter elements ($Z<32$) in the even series, the lighter isotopes are, on the average, more abundant than the heavier ones with the exception of those of He and A; whereas for almost all the heavier elements ($Z>32$), the reverse is true with the exception of the elements Zr and Nd. Since for many elements in the odd series only one isotope is known, the contrast is not so remarkable. Nevertheless, the same general tendency for an increase in the total percentage of the heavier isotopes can be seen if we tabulate the relative abundance of the lighter and heavier isotopes of some odd-numbered

elements that have at least two known isotopes (Table III).

A convenient way to visualize the foregoing result is to plot the mass numbers of all the known isotopes as a function of atomic number. Since the range within which the isotopes of the odd elements occur is very small and in many cases only one isotope is known, we plot the main isotopes only. Actually, the average range within which the isotopes occur is 7.0 for the even and 1.9 for the odd elements. Furthermore, it is to be noted that the middle point of the range for the isotopes of the even series is, in most cases, the same as the average value of the isotopes of its nearest neighbors. In some cases the value may differ by one or two units only, as shown in the parentheses in Table II. In only one case, namely Ge, does the change of the middle point by one unit result in a reversal of the order of the relative abundance of the lighter and the heavier isotopes. Therefore, for the sake of simplicity, the main isotopes of the odd series can be used as a basis for comparing the relative abundance of the even series.

In Fig. 1 the main isotopes of the odd series are represented by crosses and those of the even series by a series of dots. The change in the odd series is approximately linear and is used here as a basic line for comparison. In the region of lighter elements ($Z<31$), where the lighter isotopes of the even elements predominate, the resulting atomic weight, represented by circles, naturally comes below the middle point of the range of the isotopes, or the average of the two nearest odd ones. This results in the curve with the even atomic weight below the average of the odds, thus producing an even-lagging alternation. As the atomic number becomes higher and higher, the heavier isotopes of the even series tend to predominate. When a certain point is passed (where $Z=31$), the resulting atomic weight of even elements exceeds the average atomic weight of the neighboring odd elements. This results in the curve with even atomic weight above the average of the odds, thus producing an even-advancing alternation. The feature of increased stability and abundance of the heavier isotopes and that of the inversion of the alternation are all obviously shown in the figure. Therefore, we may conclude that the inversion of the alternation is a natural consequence of the increased stability and abundance of the heavier isotopes.

If atomic weight is to be considered as a function of atomic number, any other property of the element that is so associated with the atomic weight as to give a nonalternating quantity should also be alternating in character. If the product of the property and the atomic weight is a constant quantity, this property will alternate inversely to the manner in which the atomic weight does. In other words, when the atomic weight is an even-advancing alternate function of the atomic number, this property will change in an even-lagging alternate manner. On the other hand, if the quotient of the property and the atomic weight is constant, the property will change in the same manner as does the atomic weight. As an illustration of the first point, the law of Dulong and Petit states that the atomic heat is the same for all solid elements at ordinary temperature. The corollary should be that the specific heat (cal/g °C) of the elements must be also an inverse alternate function of the atomic number. Of course, the validity of the law of Dulong and Petit and the accuracy of specific heat measurements do not justify the tracing of this alternation, and the comparatively small alternation in the atomic weight might make the alternation in the specific heat insignificant. Nevertheless, any relationship which is to be exact between atomic weight and any other property of the elements must conform to this requirement.

It is a pleasure to thank Professors Ta-You Wu and S. T. Ma and Doctor Q. F. Soper for valuable discussions on this subject.

I TAKE the view that a theory should be a policy and not a creed, that its most important work is to suggest things which can be tried by experiment, and for this the theory should be one that is easily visualized.—J. J. THOMSON

Internationality in the Names of Scientific Concepts: A Method of Naming Concepts

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THE achievement of internationality in scientific nomenclature is a highly desirable end toward which a number of international organizations are working. The use of a common set of words, symbols and units throughout the world expedites the transfer of scientific and engineering information and eliminates the very real and shameful waste associated with recalculation and translation.

At a time like this, when there is such tragic need for international cooperation, the humblest step toward world unity should not be ignored. Compared with many projects, the achievement of international scientific nomenclature is a humble step indeed. Nevertheless, it would provide one more small but definite bond between workers in different countries. As such, even aside from the obvious practical value, international nomenclature should be given immediate and serious attention.

The present paper considers only one phase of the problem; namely, international names for scientific concepts. Present names grew up in a haphazard manner, so that the name of a given concept may be entirely unrecognizable in a foreign language. As a consequence, a scientist must memorize and keep in mind a specialized set of words for each language in which he keeps abreast of his specialty. A further complication results from the fact that most scientific words have not been coined for this purpose but have been borrowed from everyday life. Thus, even in his native language, the scientist or technician is often puzzled as to whether the word is to be interpreted in its exact scientific sense or in one of its popular senses.[1]

A study of the behavior of established scientific words leads to the following conclusions:

(*a*) If the word has also a popular meaning, it will not be accepted internationally but will be *translated* into each language in which the scientific term is needed. For example, a plot of ground was called a *feld* in Anglo-Saxon, giving the English word *field*. When the necessity arose of talking about a region of space in which an electric charge experiences a force, a new word should have been coined to express the new idea. Instead, the word *field* was employed in English, despite the rather tenuous connection between the scientific concept and a grass plot. As a result, the scientific concept is called in other languages by the translation of the common word: *champ* in French, *campo* in Italian and Spanish, *pole* in Russian.

(*b*) If a scientific name is taken from Latin, it will probably be *translated* into each language; though if the word is unfamiliar, it may be accepted as an international word. For instance, our word *velocity* is from the Latin *velocitas*. The French word is *vitesse;* the German, *Geschwindigkeit;* the Russian, *skorost*. On the other hand, a few words of Latin origin, such as *potential* and *gradient*, are international.

(*c*) If a scientific word is taken from classical Greek, the probability is high that it will be accepted with little or no change by all the languages of Europe and the Western hemisphere.

On the basis of this investigation, we recommend that the names of scientific concepts be taken from Greek. But it is not desirable to have a distinct root for each concept: a group of closely related concepts may well employ the same root with different affixes. A study has been made of suffixes that have already obtained a considerable degree of internationality. The principal ones are

-OR = a device,
-TION = a process,
-ANCE = passive property of an entity,
-ITY = passive property of a substance.

[1] Parry Moon, "A system of photometric concepts," *J. Opt. Soc. Am.* **32**, 348 (1942); "The names of physical concepts," *Am. J. Physics* **10**, 134 (1942).

To these have been added the new endings:

-ENT = per unit length,
-AGE = per unit area,
-UM = per unit volume.

The process of naming scientific concepts, as recommended in this paper, consists in selecting a few basic words from the Greek lexicon and forming others by means of the foregoing standardized endings. The method eliminates both of the serious faults—ambiguity and noninternationality—that apply to most names of scientific concepts today. The words are different from anything in common speech, and thus there is no chance of confusing exact scientific terms with vague popular terms. Also, since the new designations are not common words, there will be no attempt to translate them into other languages. They will be accepted (with, at most, slight changes in orthography) by the languages of Europe and America, thereby eliminating many misunderstandings and translational difficulties. The details of the method will be given in the following sections.

1. What is Internationality?

Etymologically speaking, the word *international* means "pertaining to more than one nation." By this definition, practically every scientific word is an "international" word. Also, English is an "international" language, as is Portuguese, since they are used officially by more than one nation. But this is not what is ordinarily meant by *international*. We shall use the word with its more common meaning, which might perhaps be better expressed by *universal* or *global*.

In the development of an international auxiliary language, an "international" word is usually considered to be one that is recognizably similar in English, French, Italian, Spanish and, if possible, German. Peano[2] lists 15,000 "international" words based on Latin, Italian, French, English and German. The research of the International Auxiliary Language Association[3] is founded on the study of English, French, Italian and Spanish. The use of the word "international" in such cases has been criticized, since a large part of the world population and over a thousand languages[4] are ignored.

The use of the word "international" in scientific terminology is somewhat less open to criticism, since scientific results are designed to appeal principally to that part of the world which is publishing an appreciable amount of scientific work in its own language. In the last decade, the bulk of scientific publication has been done in English, French, German and Russian. To these four, our paper adds four other languages in which some scientific publication is done. Further languages, such as Japanese, Polish and Georgian, have been left out of our tables for several reasons:

(*a*) Their scientific and technical literature is comparatively small.

(*b*) The language is so different from that of most scientific publication that few correlations can be found.

(*c*) Scientific dictionaries are nonexistent or unsatisfactory in these languages.

In other words, in arriving at "internationality," we have heavily weighted English and the Romance languages, simply because any other scheme seemed to be impracticable at the present time.

2. Some Word Endings in International Use

A number of endings of scientific words have achieved a considerable degree of internationality and a fairly definite scientific meaning.[1] One may mention particularly the following:[5]

-OR = a device,
-TION = a process,
-ANCE = a passive property of an entity,
-ITY = a passive property of a substance.

[2] G. Peano, *Vocabulario commune* (Cavoretto-Torino, Italy, 1915).

[3] International Auxiliary Language Association, 420 Lexington Avenue, New York. See *General Report* (1945).

[4] It is interesting to note that the whole or portions of the Christian Bible have been translated into more than a thousand dialects. See *The book of a thousand tongues* (American Bible Society, New York, 1938).

[5] After writing the paper, we found a somewhat similar tabulation in *Letter symbols for heat and thermodynamics including heat flow, ASA, Z 10.4* (Am. Standards Assoc., New York, 1943). This publication defines standard meanings for -IVITY, -ANCE and -ION. We do not agree with their meaning for -ION. The other two definitions (p. 12) are as follows:

"Terms ending in -IVITY designate characteristics of materials, normally independent of size or shape; sometimes called 'specific properties.' Examples are—conductivity and resistivity.

"Terms ending in -ANCE designate properties of a particular object, depending not only on the material, but also upon size and shape; sometimes called 'total quantities.' Examples are—conductance and transmittance."

TABLE I. Ending -OR = a Device.

English	French	Italian	Spanish	Portuguese	German	Dutch	Russian*
accumulator	accumulateur	accumulatore	acumulador	acumulador	Akkumulator	accumulator	akkumulя̂tor
alternator	alternateur	alternatore	alternador	alternador	Wechselstromgenerator	wisselstroom generator	alternator
amplifier	amplificateur	amplificatore	amplificador	amplificador	Verstärker	versterker	*usilitel*
collector	collecteur	collettore	colector	colector	Stromabnehmer	collector	kollektor
conductor	conducteur	conduttore	conductor	condutor	Leiter	geleider	*provodnik*
converter	convertisseur	convertitore	convertidor	convertedor	Umformer	omvormer	konverter
diffusor	diffuseur	diffusore	difusor	difusor	Lichtstreuungskörper	verspreider	diffuzor
generator	générateur	generatore	generador	generador	Generator	generator	generator
insulator	isolateur	isolatore	aislador	isolador	Isolator	isolator	izolя̂tor
motor	moteur	motore	motor	motor	Motor	motor	motor
oscillator	oscillateur	oscillatore	oscilador	oscilador	Oszillator	oscillator	osцillator
radiator	radiateur	radiatore	radiador	radiador	Strahlungskörper	radiator	radiator
rectifier	rédresseur	raddrizzatore	rectificador	rectificador	Gleichrichter	gelijkrichter	rektifikator
refrigerator	réfrigérateur	refrigeratore	refrigerador	refrigerador	Kälteerzeuger	*ijskast*	refrizherator
reflector	réflecteur	riflettore	reflector	reflector	Reflektor	reflector	reflektor
refractor	réfracteur	rifrattore	refractor	refractor	Lichtbrechungskörper	refractor	refraktor
regulator	régulateur	regolatore	regulador	regulador	Regler	regulateur	regulя̂tor
resonator	résonateur	risonatore	resonador	resonador	Resonator	resonator	rezonator
rotor	rotor	rotore	rotor	rotor	Läufer	rotor	rotor
stator	stator	statore	estator	estator	Ständer	stator	stator
tractor	tracteur	trattore	tractor	trator	Traktor	tractor	traktor
transformer	transformateur	trasformatore	transformador	transformador	Transformator	transformator	transformator

Total entries, 176; number of agreements, 173; percentage agreement, 98.
Total entries without German, Dutch and Russian, 110; number of agreements, 110; percentage agreement, 100.
* See footnote 12.

In the English language, many names for devices end in -OR; for example, *motor*, *generator*, *oscillator*, *tractor*, *reflector*. Table I indicates that there is a tendency to use the same word, or at least the same ending, in other languages. For instance, *motor* is unchanged in German, Spanish, Portuguese, Dutch and Russian; while in French (*moteur*) and Italian (*motore*) it is only slightly modified. Table I includes 176 entries of this kind. In 173 cases, the names are the same as in English or are easily recognizable, and in only three cases is a different word used.

In making this count, we considered -ER as equivalent to -OR. The French -EUR and the Italian -ORE are also taken as equivalent to the English -OR, since there could be no misunderstanding caused by these slight differences. Of the three words that do not fit into the international pattern, one is in Dutch and two are in Russian. These words are italicized in the table. Evidently the ending -OR is a well-established international way to designate a device.

A similar condition exists with the ending -TION employed to designate a process. In this class belong such words as *amplification*, *adaptation*, *illumination*, *ionization*. Some of these words are listed in Table II. Among 216 entries, the English ending or a close approximation to it is employed in 174 cases, while a different ending appears 42 times (italicized words of Table II). The agreement is not as good as in Table I, mainly because Germans and Dutch have not taken the trouble to systematize their notation. Taking into account only the first five languages of the table, one gets a 98-percent agreement, which compares favorably with the agreement in Table I.

These numerical values are, of course, somewhat arbitrary. It is a question whether the Portuguese *-ção* should be considered as equivalent to -TION, though we have so considered it. If *-ção* is accepted, then it seems reasonable to accept also the Dutch -TIE and the Russian -SI͡A. Our purpose in including the tables is to show that there is a considerable degree of internationality in the endings of present scientific words. This conclusion is substantiated by the tables. The exact numerical values are unimportant.

An ending that has become international partly because of the activities of electrical engineers is -ANCE. It indicates a passive property of an entity. Examples are *resistance*, *impedance*, *reluctance*. Table III gives some of these words and shows that this ending has been accepted by most European languages. The Italian -ANZA and -ENZA have been considered as equivalent in obtaining the numerical summary at the bottom of the table.

TABLE II. Ending -TION = a Process.

English	French	Italian	Spanish	Portuguese	German	Dutch	Russian
accomodation	accommodation	*accomodamento*	acomodación	acomodação	Akkommodation	accommodatie	akkomadat͡sɪja
adaptation	adaptation	*adattamento*	adaptación	adaptação	Adaptation	*aanpassing*	adapta͡tsɪja
amplification	amplification	amplificazione	amplificación	amplificação	*Verstärkung*	*versterking*	*usilenie*
attenuation	atténuation	attenuazione	atenuación	atenuação	*Dämpfung*	*verzwakking*	*zatukhanie*
calibration	graduation	calibrazione	calibración	graduação	*Eichung*	*gradering*	*graduirovka*
circulation	circulation	circolazione	circulación	circulação	*Umlauf*	circulatie	t͡sɪrkuli͡atsɪja
concentration	concentration	concentrazione	concentración	concentração	Konzentration	concentratie	kont͡sentra͡tsɪja
condensation	condensation	condensazione	condensación	condensação	Kondensation	condensatie	kondensat͡sɪja
designation	désignation	designazione	designación	designação	*Bezeichnung*	*aanwijzen*	*ukazanie*
dissociation	dissociation	dissociazione	disociación	dissociação	Dissoziation	dissociatie	dissot͡sɪa͡tsɪja
electrification	électrification	elettrificazione	electrificación	electrificação	*Elektrifizierung*	electrificatie	ėlektrifikat͡sɪja
elongation	élongation	elongazione	elongación	*alongamento*	*Verlängerung*	*rek*	*udlinenie*
excitation	excitation	eccitazione	excitación	excitação	*Erregung*	excitatie	*vozbuzhdenie*
filtration	filtration	filtrazione	filtración	filtração	*Filterung*	*filtering*	filtra͡tsɪja
formation	formation	formazione	formación	formação	Formation	formatie	forma͡tsɪja
graduation	graduation	graduazione	graduación	graduação	*Teilung*	*gradering*	gradat͡sɪja
indication	indication	indicazione	indicación	indicação	*Anzeige*	*aanwijsing*	*ukazanie*
installation	installation	installazione	instalación	instalação	*Anlage*	installatie	installa͡tsɪja
ionization	ionisation	ionizzazione	ionización	ionização	Ionisation	ionisatie	ionizat͡sɪja
irradiation	irradiation	irradiazione	irradiación	irradiação	*Bestrahlung*	*bestraling*	Irradiat͡sɪja
magnetization	aimantation	magnetizzazione	imantación	magnetisação	*Magnetisierung*	magnetisatie	*namagnichivanie*
modulation	modulation	modulazione	modulación	modulação	*Modulierung*	modulatie	modula͡tsɪja
oxidation	oxidation	ossidazione	oxidación	oxidação	Oxydation	oxydatie	*okislenie*
polarization	polarisation	polarizzazione	polarización	polarisação	Polarisation	polarisatie	polɪrizat͡sɪja
saturation	saturation	saturazione	saturación	saturação	*Sättigung*	*verzadiging*	*nasyshchenie*
standardization	standardisation	standardizzazione	normalización	normalização	*Normalisierung*	*normalisering*	standartizat͡sɪja
transformation	transformation	transformazione	transformación	transformação	Transformation	transformatie	transforma͡tsɪja

Total entries, 216; number of agreements, 174; percentage agreement, 80.
Total entries without German, Dutch and Russian, 135; number of agreements, 132; percentage agreement, 98.

Table IV lists words ending in -ITY, indicating a passive property of a substance. Examples are *resistivity*, *permeability*, *viscosity*, *density*. The corresponding ending in French is *-ité*. In Spanish it is *-idad*, in Portuguese *-idade*, in Italian *-ità*, and in German *-ität*. The internationality of this ending is thus somewhat inferior to the previous ones, though none of the foregoing forms is sufficiently different to cause confusion.

The data given at the bottoms of Tables I to IV indicate that, for the eight languages considered, the endings -OR, -TION, -ANCE and -ITY may be regarded as international. In a total of 564 entries, there is an agreement in 470 cases (83 percent). If German, Dutch and Russian are omitted, there is agreement in 349 out of 355 cases (98 percent).

As would be expected in any natural language, there is a lack of complete consistency. It is easy to find words in which the foregoing endings are used with other meanings: for instance, *aviator* is not a device, and *velocity* is not a property of a substance. But these exceptions do not affect the desirability of associating definite scientific meanings with definite word endings.

The foregoing suffixes are by no means the only ones used by scientists. A number of other word endings have a degree of internationality and suggest fairly definite meanings. For *devices*, besides the ending -OR, we have

-ER (as in *rectifier*, *adapter*),
-MENT (as in *filament*, *pediment*),
-ING (as in a *filling*),
-ANT (as in *pendant*).

The ending -TION may mean a process as in Table II, or it may mean the result of a process. For instance, the word *graduation* means the process of fixing a scale, and it means also the physical scale, as on a chemical graduate. Another ending indicating a process is -ING, as in *lighting* and *welding*.

For a *practitioner*, there are

-IST (*chemist*, *artist*),
-OR (*aviator*, *doctor*),
-ER (*driver*).

To indicate a *measuring device*, we have

-METER (*voltmeter*, *accelerometer*);

for a device that gives a pictorial or graphical indication,

-GRAPH (*oscillograph*);

for a device that gives a visual indication,

-SCOPE (*telescope*, *microscope*).

All these and many other suffixes are employed. Prefixes are also used; but for the purpose of this investigation, the word endings given in Tables I to IV seem to be of particular importance; and their use, with the meanings given

TABLE III. Ending -ANCE = passive property of a device.

English	French	Italian	Spanish	Portuguese	German	Dutch	Russian
admittance	admittance	ammettenza	admitancia	admitância	*Scheinleitwert*	*admittantie*	*polnaя provodimost*
capacitance	capacitance	capacitanza	capacitancia	capacitância	*Kapasität*	*capaciteit*	*emkost*
conductance	conductance	conduttanza	conductancia	conductância	Konduktanz	*geleiding*	*provodimost*
impedance	impédance	impedenza	impedancia	impedância	Impedanz	*impedantie*	Impedanѕ
inductance	inductance	induttanza	inductancia	inductância	Induktanz	*inductie*	*induktivnoe soprotivlenie*
permeance	perméance	permeanza	permeancia	permeância	*magnetischer Leitwert*		*magnitnaя provodimost*
reactance	réactance	reattanza	reactancia	reactância	Reaktanz		*reaktivnoe soprotivlenie*
reluctance	réluctance	riluttanza	reluctancia	relutância	Reluktanz		*magnitnoe soprotivlenie*
resistance	résistance	resistenza	resistencia	resistência	*Widerstand*	*weerstand*	*soprotivlenie*
susceptance	susceptance	suscettanza	susceptancia	susceptância	*Blindleitwert*		*reaktivnaя provodimost*

Total entries, 76; number of agreements, 56; percentage agreement, 74.
Total entries without German, Dutch and Russian, 50; number of agreements, 50; percentage agreement, 100.

at the beginning of this section, should be encouraged in the coining of new scientific names.

3. Active and Passive Concepts

It seems advisable to make a sharp distinction between *active* and *passive* concepts. This distinction is exemplified in electric circuit theory, where the active concepts of electromotive force, current, power and energy are distinguished from the passive parameters of the circuit by use of distinctive endings for the names of the latter. The passive characteristics of the circuit elements are called by such names as *resist*ANCE, *conduct*ANCE, *react*ANCE, *induct*ANCE, *capacit*ANCE, *imped*ANCE. When the construction of a device is considered, the passive properties of the materials must be indicated—the *resistiv*ITY of copper, the *permeabil*ITY of iron, the *permittiv*ITY of mica. In no case are the endings -ANCE and -ITY employed with an active concept: there is no talk about "energity" or "voltance" or "electromotance."

The same principle is employed, though to a lesser extent, in other branches of physics. Electrical theory, being a comparatively recent development, has found a more logical nomenclature than some of the earlier parts of physics. It serves as a particularly good example of the value of distinguishing between active and passive concepts.

In view of this distinction, it is unfortunate that several attempts have been made recently to use -ANCE and -ITY in coining names for *active* concepts.[6] Such a step tends to confuse the international scientific meanings that are growing up with respect to these word endings.

4. Greek and Latin Roots

In the formation of new scientific words, one must consider both the basic words and the

TABLE IV. Ending -ITY = passive property of a substance.

English	French	Italian	Spanish	Portuguese	German	Dutch	Russian
absorptivity	absorptivité	assorbibilità	absorbibilidad	absorbibilidade	Absorbilität	*absorbeerbaarheid*	*poglosh̆aemost*
compressibility	compressibilité	compressibilità	compresibilidad	compresibilidade	*Pressbarkeit*	*samendrukbaarheid*	*szhimaemost*
conductivity	conductivité	conduttività	conductividad	conductividade	*Leitfähigkeit*	*geleidingsvermogen*	*provodimost*
density	densité	densità	densidad	densidade	*Dichte*	*dichtheid*	*plotnost*
elasticity	élasticité	elasticità	elasticidad	elasticidade	Elastizität	elasticiteit	*elastichnost*
fluidity	fluidité	fluidità	*fluidez*	*fluidez*	Fluidität	*vloeibaarheid*	*plavnost*
permeability	perméabilité	permeabilità	permeabilidad	permeabilidade	Permeabilität	permeabiliteit	*magnitnaя pronitaemost*
resistivity	résistivité	resistività	resistividad	resistividade	*spezifischer Widerstand*	*soortelijkeweerstand*	*udelnoe soprotivlenie*
rigidity	rigidité	rigidità	*rigidez*	inflexibilidade	*Steifheit*	*stijfheid*	*zhestkost*
solubility	solubilité	solubilità	solubilidad	solubilidade	*Löslgkeit*	*oplosbaarheid*	*rastvorimost*
susceptibility	susceptibilité	suscettibilità	susceptibilidad	susceptibilidade	Susseptibilität	susceptibiliteit	*magnitnaя vospriimchivost*
viscosity	viscosité	viscosità	viscosidad	viscosidade	Viskosität	viscositeit	*vi̇zkost*

Total entries, 96; number of agreements, 67; percentage agreement, 70.
Total entries without German, Dutch and Russian, 60; number of agreements, 57; percentage agreement, 95.

[6] "Report of the Colorimetry Committee," *J. Opt. Soc. Am.*, **34**, 246 (1944); W. E. Forsythe, *Measurement of radiant energy* (McGraw-Hill, New York, 1937), p. 3.

TABLE V. Some scientific words, not derived from Greek.

English	From	French	German	Russian
acceleration	Latin	accélération	Beschleunigung	uskorenīe
angle	Latin	angle	Winkel	ugol
area	Latin	aire	Fläche	ploshchad
attenuation	Latin	atténuation	Verdünnung	rastvorenie
bridge (Wheatstone)	Anglo-Saxon	pont	Brücke	most
brush (of electric generator)	Old French	balai	Bürste	shchetka
buzzer (electric)	—	vibrateur	Summer	avtomatīcheskiĭ preryvatel
current (electric)	Latin	courant	Strom	tok
damping	German	amortissement	Dämpfung	zatukhanīe
dial	Latin	cadran	Zifferblatt	t͡sīferblat
distance	Latin	longueur	Strecke	razstoi͡anīe
dry cell (electric)	—	pile sèche	Trockenelement	sukhoi ėlement
efficiency	Latin	rendement	Wirkungsgrad	otdacha
error	Latin	erreur	Fehler	oshībka
field (magnetic)	Anglo-Saxon	champ	Feld	pole
force	Latin	force	Kraft	sīla
fuse (electric)	Latin	fusible	Schmelzeinsatz	plavkiĭ predokhranitel
glare	Middle English	éblouissement	Blendung	bleskost
grid (of vacuum tube)	Middle English	grille	Gitter	setka
hardness	Anglo-Saxon	durété	Härtegrad	tverdost
hue	Anglo-Saxon	teinte	Farbton	t͡svetovoĭ ton
humidity	Latin	humidité	Feuchtigkeit	vlazhnost
image	Latin	image	Bild	īzobrazhenīe
key (telegraph)	Anglo-Saxon	clé	Taste	klīu̇ch
length	Anglo-Saxon	longuer	Strecke	dlīna
light	Anglo-Saxon	lumière	Licht	svet
loudspeaker	Anglo-Saxon	haut-parleur	Lautsprecher	gromkogovorītel
nucleus	Latin	noyau	Kern	i͡adro
plug (electric)	Middle Dutch	fiche	Stöpsel	kontaktnyĭ shtepsel
rectifier	Latin	redresseur	Gleichrichter	vypri͡amītel
saturation	Latin	saturation	Sättigung	nasyshchennost
scale	Old Norse	échelle	Skale	masshtab
spark	Anglo-Saxon	étincelle	Funke	īskra
sparkgap	Anglo-Saxon	éclateur	Funkenstrecke	razri͡adnīk
stress	Latin	sollicitation	Beanspruchung	usīlie
switch (electric)	Middle Dutch	interrupteur	Schalter	preryvatel
time	Anglo-Saxon	temps	Zeit	vremi͡a
turbulence	Latin	turbulence	Unruhe	burnost
velocity	Latin	vitesse	Geschwindigkeit	skorost
wave	Anglo-Saxon	onde	Welle	volna
work	Anglo-Saxon	ouvrage	Arbeit	rabota

specialized endings that are to be used with these words. The endings were treated in SEC. 2. We now turn to a consideration of the basic words. It is of course possible to form these words *ab initio* by employing arbitrary combinations of letters. The experience of a number of investigators in the formation of *a priori* international languages,[7] however, indicates that the method is impracticable. Another way is to rely on classical Greek and Latin.[8] The trouble with Latin for scientific purposes is that lay speech in the Romance languages and in English contains so much that is derived from Latin. As a result, the investigator finds difficulty in obtaining roots that do not suggest ideas of common speech. For this reason, Greek forms a more feasible source of scientific terms than Latin.

To see how well this principle has worked in the

[7] See, for instance, F. Bodmer, *The loom of language*, L. Hogben, ed. (W. W. Norton, New York, 1944), p. 457.

[8] C. G. Darwin, "Terminology in physics," *Nature* **138**, 908 (1936).

past, we selected 210 scientific words, principally from physics and engineering. As a criterion of internationality, we considered in this case that the word should be essentially unchanged in English, French, German and Russian. If the English and French versions are the same, the word is generally accepted also in Italian, Spanish and Portuguese. If English and German are the same, the word is ordinarily accepted also in Dutch, Swedish, Danish and Norwegian. Thus this simple four-language criterion gives an idea of internationality without the complexity associated with a consideration of the other languages.

The 210 words were classified into two groups: (i) those directly from Greek, and (ii) those from all other sources, including Latin. Of the 119 words in the first group (Greek), 82 percent were essentially the same in English, French, German and Russian. Of the 91 words in the second group (non-Greek), only 38 percent were international. Thus the scientific words based on classical Greek were decidedly more international than those derived from Latin, though the correlation was not perfect.

Table V shows how typical Latin words have behaved when employed in scientific terminology. Whenever a word is somewhat familiar in any of the ethnic languages, there is a tendency to *translate* it into each of the others rather than to accept it without alteration. For example, the Latin word *acceleratio* becomes *acceleration* in English, which is translated into *Beschleunigung* in German and *uskorenīe* in Russian; and the English *efficiency* (from Latin *efficio*) is called *rendement* in French, *Wirkungsgrad* in German, and *otdacha* in Russian. Evidently this is not internationality.

The behavior of typical Greek words is shown in Table VI. For example, the English *acoustics* comes from the Greek ἀκουστικός. In French it is written *acoustique;* in German, *Akustik;* and in Russian, *akustīka.* Of course there is nothing magic about classical Greek that guarantees internationality. Some scientific words have been borrowed from other languages with good results. For instance, *azimuth* is from Arabian. In French it is *azimut;* in German, *Azimut;* and in Russian, *azimut.* Latin roots, when sufficiently unfamiliar, have also been satisfactory in a number of cases.

TABLE VI. Some scientific words derived from Greek.

English	French	German	Russian
acoustics	acoustique	Akustik	akustīka
actinometer	actinomètre	Aktinometer	aktinometr
aerodynamics	aérodynamique	Aerodynamik	aerodinamika
anode	anode	Anode	anod
arithmetic	arithmétique	Arithmetik	arifmetika
asteroid	astéroïde	Asteroid	asteroid
astronomy	astronomie	Astronomie	astronomīia
atom	atom	Atom	atom
barometer	baromètre	Barometer	barometr
bibliography	bibliographie	Bibliographie	bibliographīia
bolometer	bolomètre	Bolometer	bolometr
botany	botanique	Botanik	botanika
cathode	cathode	Kathode	katod
chrome	chrome	Chrom	khrom
chronometer	chronomètre	Chronometer	khronometr
cosmogony	cosmogénie	Kosmogonie	kosmogonīia
cosmos	cosmos	Kosmos	kosmos
crater	cratère	Krater	krater
criterion	criterium	Kriterium	kriterīĭ
crystal	cristal	Kristal	kristal
cycle	cycle	Cycle	tsīkl
dielectric	diélectrique	Dielektrikum	dielektrik
dynamics	dynamique	Dynamik	dinamika
dynamo	dynamo	Dynamo	dinamo
electricity	électricité	Elektrizität	elektrichestvo
electrode	électrode	Elektrode	elektrod
electrolysis	électrolyse	Elektrolyse	elektroliz
electron	électron	Elektron	elektron
energy	energie	Energie	energīia
galvanometer	galvanomètre	Galvanometer	galvanometr
geometry	géométrie	Geometrie	geometrīia
geography	géographie	Geographie	geografīia
geophysics	géophysique	Geophysik	geofizika
gloss	glose	Glosse	glossa
graphic	graphique	graphisch	graphicheskīĭ
hypothesis	hypothèse	Hypothese	gipoteza
hysteresis	hystérésis	Hysterese	gisterezis
ion	ion	Ion	ion
lamp	lampe	Lampe	lampa
machine	machine	Maschine	mashīna
mass	masse	Masse	massa
mathematics	mathématiques	Mathematik	matematika
mechanics	mécanique	Mechanik	mekhanika
mechanism	mécanisme	Mechanismus	mekhanizm
metal	métal	Metall	metall
meter (length)	mètre	Meter	metr
micrometer	micromètre	Mikrometer	mikrometr
micron	micron	Mikron	mikron
microphone	microphone	Mikrophon	mikrofon
microscope	microscope	Mikroskop	mikroskop
monochromator	monochromateur	Monochromator	monokhromator
optics	optique	Optik	optika
parabola	parabole	Parabel	parabola
period	période	Period	period
phonetics	phonétique	Phonetik	fonetika
phonograph	phonographe	Phonograph	fonograf
phosphor	phosphore	Phosphor	fosfor
photograph	photographie	Photographie	fotografīia
photometer	photomètre	Photometer	fotometr
physics	physique	Physik	fizika
physiology	physiologie	Physiologie	fiziologīia
plasma	plasma	Plasma	plazma
polytechnic	polytechnique	polytechnisch	politekhnicheskīĭ
prism	prisme	Prisma	prizma
solenoid	solenoïde	Solenoid	solenoid
pyrometer	pyromètre	Pyrometer	pirometr
statics	statique	Statik	statika
stereoscope	stéréoscope	Stereoskop	stereoskop
symmetry	symétrie	Symmetrie	simmetrīia
synchronism	synchronisme	Synchronismus	sinkhronizm
telegraph	télégraphe	Telegraph	telegraf
telephone	téléphone	Telephon	telefon
telescope	téléscope	Teleskop	teleskop
thermometer	thermomètre	Thermometer	termometr
topography	topographie	Topographie	topografīia
zoology	zoologie	Zoologie	zoologīia

For example, the Latin *quantum* is unchanged in English and French. In German, it is written *Quantum* and in Russian, *kvanta*.

One concludes that satisfactory scientific words can be obtained in various ways. Probably the simplest and surest method of achieving internationality, however, is to take words from classical Greek.

5. A Method of Naming Physical Concepts

As stated previously,[1] the names of physical concepts should satisfy four requirements: (i) nonambiguity, (ii) internationality, (iii) simplicity and (iv) euphony. If the name of a scientific concept is borrowed from daily life, as is usually the case, there is always a chance of misunderstanding. The reader must try to decide from the context whether the word is used in its precise scientific sense or with one of its popular meanings. The decision is not always easy.

The best way of overcoming this ambiguity, as indicated in SEC. 4, is to choose words from classical Greek. These words should be short and euphonious and should be similar to as few modern words as possible. The wide use of Greek terms in biology and medicine has been satisfactory. In nearly every case, the Greek word has come into use in all European languages with little modification, thus satisfying the requirement of internationality. In physics and engineering, we have many Greek-derived names of devices and a few names for concepts. (See Table VI.)

The next step is to decide on standard word endings to which precise scientific meanings are assigned. Many Greek names end in -OS, and it is convenient to retain this ending in English whenever a more specialized ending is not needed. It is also convenient to have endings signifying *per unit length*, *per unit area* and *per unit volume*.

TABLE VII. Proposed word endings for terms in English.

Ending	Meaning
-OS	basic concept
-ENT	per unit length
-AGE	per unit area
-UM	per unit volume
-OR	a device
-TION	a process
-ANCE	passive property of an entity
-ITY	passive property of a substance

Since 1941 we have been using[1] the three endings:

-ENT = per unit length,
-AGE = per unit area,
-UM = per unit volume.

For example, if the basic concept of *electric charge* is called *electros*, as suggested in a previous paper,[1] then the charge per unit length of wire is called *electrosent*, the charge per unit area of surface is *electrosage*,[9] and the charge per unit volume is *electrosum*. This procedure eliminates the ambiguity that occurs at present when "charge density" is used loosely for all three quantities. Similarly, if radiant *phos* (radiant energy) is the basic concept, then *phosent* is the energy radiated per unit length of an incandescent filament or a fluorescent tube, *phosage* is the energy radiated per unit area, and *phosum* is the energy radiated per unit volume.

An alternative way would be to use the Greek *root* instead of the Greek *word* (masculine nominative singular). Thus instead of *elektrosent*, one would say *elektrent;* instead of *elektrosage*, *elektrage;* and instead of *elektrosum*, *elektrum*. Since, however, we have already forsaken the classical method in our arbitrary choice of the word and in the use of suffixes that are not Greek, there seems to be no reason why we should not abandon the classical method still further by building on the nominative singular instead of on the root. The new method makes more obvious the intimate relations among a group of concepts.

Theoretically, there might be an advantage in employing a single Greek root for each branch of physics and taking care of all subsidiary concepts by means of specialized endings. For instance, if electric charge is called *elektros*, then electric current would be called *elektros* plus an ending denoting *per unit time*. The same ending could be used to change the new word for *energy* to a word denoting *power*. A similar procedure would apply to other concepts. After experimenting with this method for some time, however, we concluded that for active concepts the best compromise was obtained by using only the four endings -OS, -ENT, -AGE and -UM.

Besides the foregoing new endings, we shall use the international endings given in Tables I to IV. In particular, the endings -ANCE and -ITY will be reserved for *passive concepts* and will indicate whether the property of a device or the property of a material is meant. Among the words using -ANCE may be mentioned *reflectance*, *absorptance* and *transmittance;* also *logance* (from Greek λόγος) and *domance* (from δόμος). A new word ending in -ITY is *afantivity* (from Greek ἄφαντος = made invisible, blotted out) which specifies the light-absorbing property of a medium.

[9] The -AGE is pronounced as in French: *e lek tro sazh'*. The other words are pronounced *e lek' tros* and *e lek tros' ent*.

TABLE VIII. Proposed word endings.

Meaning	International	English	French	Italian	Spanish	Portuguese	German	Dutch	Russian
Basic concept	-oso	-os	-osse	-oso	-oso	-oso	-os	-os	-os
Per unit length	-ento	-ent	-ent	-ento	-ento	-ento	-ent	-ent	-ent
Per unit area	-ago	-age	-age	-aggio	-ago	-ago	-ag	-ag	-azh
Per unit volume	-omo	-um	-um	-umo	-umo	-umo	-um	-um	-um
A device	-oro	-or	-eur	-ore	-or	-or	-or	-or	-or
A process	-cio	-tion	-tion	-zione	-ción	-ção	-tion	-tie	-tsiia
Passive property of a device	-anco	-ance	-ance	-anza	-ancia	-ância	-anz	-antie	-ants
Passive property of a substance	-ito	-ity	-ité	-ità	-idad	-idade	-ität	-iteit	-ito

A summary of all the proposed endings is given in Table VII. This table applies to the English language. Obviously, slight changes will be necessary to obtain the most satisfactory words in other languages.[10]

Table VIII lists the recommended word endings[11] for a number of languages. For instance, *electric charge* will be called *elektroso* in International, Italian, Spanish and Portuguese; *electros* in English and Dutch; *Elektros* in German; *electrosse* in French; and *elektros* in Russian.[12] Radiant energy per unit area is *fosago* in International; *phosage* in English and French; *Phosag* in German; *phosag* in Dutch; *fosago* in Spanish and Portuguese; *fosaggio* in Italian. Anyone, writing in any language, may use the international word (second column of Table VIII), whose spelling is entirely phonetic, if he prefers it to the modification suggested for his national language.

Most of the present names for physical concepts are unsatisfactory. The words do not have unique meanings and therefore introduce ambiguity. Also they are not international. The foregoing discussion has shown how Greek words can be used for basic concepts and how an international set of word endings can be employed to obtain sets of names that are both unambiguous and international. In a subsequent paper we shall apply these principles to specific examples: the photometric, radiometric and colorometric concepts.

[10] In particular, the recommended endings must be applicable to the artificial international languages. To accomplish this modification, we add an *o*, which signifies a noun in Esperanto, Ido and Iala K^3. Artificial languages of the naturalistic type may use either the endings of Table VII or those with an added *o*.

A brief explanation of Esperanto is given in C. A. Connor and D. F. Connor, *Esperanto* (S. F. Vanni, New York, 1944). Numerous other textbooks are available, including: L. Zamenhof, *Krestomatio de Esperanto* (Paris, 1903); W. S. Benson, *Universala Esperanto metodo* (Newark, N. J., 1932). Surveys of the international language movement are given by Couturat and Leau, *Histoire de la langue universelle* (Paris, 1903); *Les nouvelles langues internationales* (Paris, 1907); A. L. Guérard, *A short history of the international language movement* (London, 1922); P. E. Stojan, *Bibliografio de internacia lingvo* (Universala Esperanto-Asocio, Geneva, 1929).

[11] Various dictionaries were consulted. Among the most useful were *International electrotechnical vocabulary* (International Electrotechnical Comm., London, 1938); L. D. Belkind, *Dictionary of lighting terminology* (Moscow, 1939); *Vocabulaire téléphonique* (Comite Consultatif *International Téléphonique*, Paris, 1938); E. Slater, *Pitman's technical dictionary* (Pitman and Sons, London, 1929); L. L. Sell, *English-Spanish technical dictionary* (McGraw-Hill, New York, 1942).

[12] For convenience in comparing Russian terms with those of other languages, we have transliterated the Russian words, using the Library of Congress method.

TRUE scientists have never been nationalists, nor do they vaunt political creeds; even in times of civil war and revolution they may be looked to for aloofness from the passions and reprisals of strife.—DONALD CULROSS PEATTIE, *Green Laurels.*

A Study of Manometric Flames

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THE scientific investigation of the phenomena associated with sound has progressed in the present century to an unparalleled degree. It has been said that more progress has been made in the science of sound in the present century than in all the preceding centuries. Yet it is less than a dozen years since D. C. Miller stated:[1]

> There is not now any theoretical formula by which one can derive, without the aid of empirical information, the dimensions of an organ pipe which will give a specified tone. The flute is the simplest of wind instruments, yet one cannot even approximately calculate the length of a flute tube which will sound a given note; one cannot by theoretical calculation locate any finger-hole on a flute tube which will produce a given tone.

The science of sound may be said to have started about 550 B. C. with the investigations of Pythagoras on vibrating strings and on musical intervals and ratios. Very little more appears to have been done until the sixteenth century when Mersenne and Galileo[2] investigated the laws relating to vibrating strings, the speed of sound and other fundamental phenomena in sound. Considerable progress was again made in the nineteenth century by Helmholtz, Koenig and Rayleigh.

Karl Rudolph Koenig is generally remembered for the acoustical apparatus which he constructed, which was always original in design and of great precision. No inferior apparatus ever left his workshop. In 1851, after obtaining the doctorate at the University of Königberg in Prussia, he went to Paris where he apprenticed himself to a famous violin maker, later going into acoustical instrument making himself. In 1862 he[3–5] invented a new method for visually observing sound waves. Koenig states:[4]

> The new instrument, on the use of which my method is founded, and to which I have given the name of *Manometric Capsule*, consists of a cavity in a wooden plate, whose orifice is closed by a thin membrane. Illuminating gas may be introduced into this cavity through a pipe—a second pipe, terminating in a gas-burner, giving means for exit and ignition.
>
> Now, if the air before the membrane be rendered suddenly of greater density, the membrane will of course be driven inwards, and thus expel the gas and cause the flame to rise quickly. If, on the contrary, the air be suddenly rarefied, the membrane becomes drawn outwards, the space within momentarily increased, the gas expanded, and the flame lowered.

This manometric-flame apparatus together with drawings of the vibratory movements made by sounds was exhibited by Koenig at the international Exhibition in London in 1862. The motion of the small flame, about 2 cm high, caused by audible sound waves acting on the membrane was much too rapid to be observed directly by the eye. Consequently Koenig used a

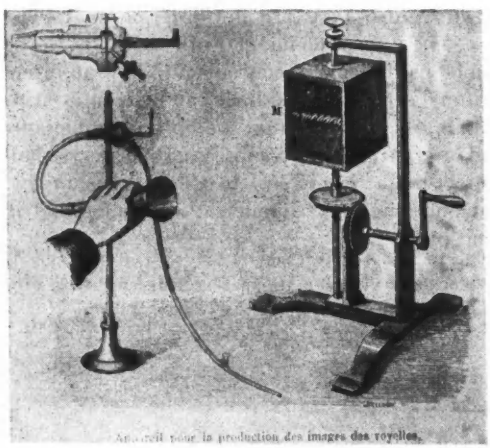

FIG. 1. Koenig's apparatus, showing the manometric flame and the rotating mirror for examining the flame.

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[1] D. C. Miller, *Anecedotal history of the science of sound* (Macmillan, 1935), p. 43.

[2] Mersenne, *Harmonie universelle* (Paris, 1636); Galileo, *Two new sciences*, tr. by H. Crew and A. DeSalvio (Northwestern Univ. Press), p. 95.

[3] Koenig, *Quelques expériences d'acoustique* (Paris, 1882), Chap. VII. Our Figs. 1, 2, 6 and 8 are reproduced from this book.

[4] R. Koenig, *Phil. Mag.* **45**, 1 (1873).

[5] R. Koenig, *Phil. Mag.* **45**, 105 (1873).

rotating mirror (Fig. 1) and observed the images in the mirror.* All the records left by Koenig are hand drawings of the images of the flame in the rotating mirror. He also made acoustical resonators of the type first devised by Helmholtz and used these with manometric flames for the analysis of sounds. With this apparatus Koenig studied simple notes and combinations of known simple notes with a view to analyzing the notes contained in various vowel sounds.

In this country E. Merritt[6] at Cornell University devised a method of photographing the manometric flame and applied it to the study of a number of vowel sounds. In these experiments the images of the vibrating flame were focused on a slit in front of a photographic plate which could be moved rapidly in a horizontal direction. About this time Hallock[7] of Columbia University also worked on the photography of manometric flames along much the same lines as Merritt. He states in this article that it is not possible to photograph the images in a four-sided rotating mirror because of irregularities in the spacing and the surfaces of the mirrors. The authors did not find this to be the case even with a mirror that was made about the time Hallock wrote his article.

Since there are many pieces of apparatus in this laboratory similar to those used by Koenig, it was decided to investigate the manometric flame and to compare it with a microphone-oscillograph combination as a means of analyzing sounds. The apparatus used in these experiments is similar to that shown in Fig. 2, which was used by Koenig. Sounds of known frequencies are produced by exciting the resonators with jets of air blown across the mouths of the resonators. The resonators are so constructed that the notes produced form a geometric series, starting with the largest resonator of frequency 128 vib/sec and proceeding to the smallest resonator having a frequency of 1024 vib/sec. The notation on the resonators, representing the different frequencies, is ut_2, ut_3, sol_3, ut_4, mi_4, sol_4, 7 and ut_5. It is interesting to note that the "frequencies" given

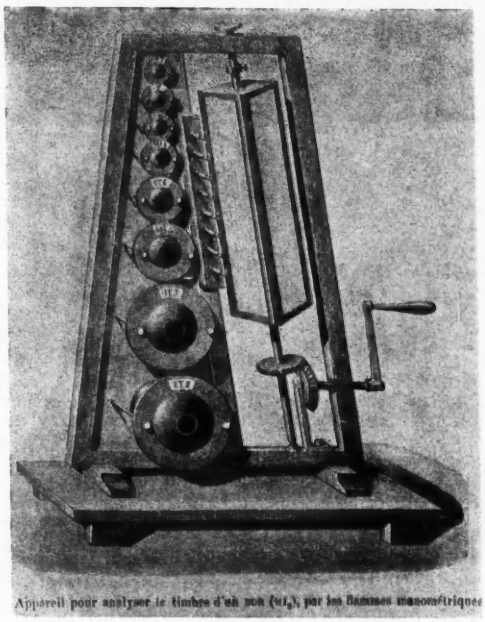

FIG. 2. Koenig's apparatus with Helmholtz resonators, manometric flames and rotating mirror.

by Koenig are twice those given here, since it was the custom in France in the nineteenth century to measure frequencies in terms of "simple vibrations," that is, halves of cycles per second. Each resonator has a small opening and pipe at the far end so that a rubber tube can be connected from it to the manometric capsule. Rarefactions and compressions produced by the notes in the resonators are transmitted through the air in the rubber tubes to the manometric capsules, thus exciting the flames.

It was found that the natural gas available in Wooster was not capable of being used for a manometric flame, presumably because of the low speed of travel of a flame in the gas. A mixture of hydrogen and acetylene was found to be satisfactory for the flames, although the composition of the mixture was not critical. Using a four-sided mirror and a Cenco rotator for driving, we found that the images of the flame could be photographed at about $f/8$ in 0.1 sec. The photographs of the flame show a small straight portion at the base with a sloping portion tapering off to a point. This is followed by a blank

* The rotating mirror was first used in a similar manner by Wheatstone in 1834 for observing electric sparks.

[6] E. Merritt, *Physical Rev.* 1, 166 (1893); E. L. Nichols and E. Merritt, *Physical Rev.* 7, 93 (1898).

[7] W. Hallock, *Physical Rev.* 2, 305 (1894).

FIG. 3. Photographs of images of the manometric flames when viewed in the rotating mirror at speeds of 175 and 91 rev/min, respectively.

portion corresponding to such low intensity of the flame that it does not register on the photographic plate. The space occupied by the brighter and less bright regions and the steepness of the sloping portions depend on the speed of rotation of the mirror (Fig. 3) as well as on the frequency of the note.

The frequency of the note produced in the resonator is calculated from the distance d separating two successive blackened portions or unblackened portions and other parameters as shown in the following calculation. In Fig. 4 let F represent the manometric flame, M the rotating mirror, L the lens of the camera and P the photographic plate or film. The successive blackened portions of the plate come from images s_1 and s_2, corresponding to two successive compressions arriving at the flame during a time equal to the period T of the vibrations. If ω is the angular speed of the mirror, then during the time T the mirror turns through an angle ωT and the two successive images of the flame are separated by a distance s_1s_2, or $2\omega Ta$, where a is the distance of the flame from the mirror. From Fig. 4 it is seen that $s_1s_2/(b+a)=d/c$. Hence

$$2\omega Ta/(b+a)=d/c,$$

or

$$T=d(b+a)/2\omega ac. \qquad (1)$$

Since a four-sided mirror was used, the axis of rotation of the mirror is not at the center of the mirror as shown in Fig. 4, but a short distance away, at the center of the square formed by the mirrors. This necessitates a small correction in Eq. (1). We measured the various quantities appearing in Eq. (1) and calculated the value of the period T and the frequency f of several notes produced by the resonators. These frequencies agreed very well with those assigned to the resonators.

In order to compare the manometric flame with the cathode-ray oscillograph as a means of analyzing sound, two pure tones of frequencies 256 and 384 vib/sec were produced in the resonators. These were connected to the manometric flames, and the images of the flames in the rotating mirror were photographed [Fig. 5(*a*) and (*b*)].[8] The rubber tubes from the two sounding resonators were then connected together by a T-joint to a single manometric flame and the resultant compound vibrations photographed [Fig. 5(*c*)]. These photographs may be compared with Koenig's drawings of two sounds shown in Fig. 6. Photographs were then made of the wave forms of these same sounds as produced by an oscillograph with a microphone and amplifier (see Fig. 7). There is no doubt that the oscillograph is the simplest and most fruitful method of analyzing the wave forms of sound.

An interesting experiment was carried out by Koenig to show interference of sound waves.

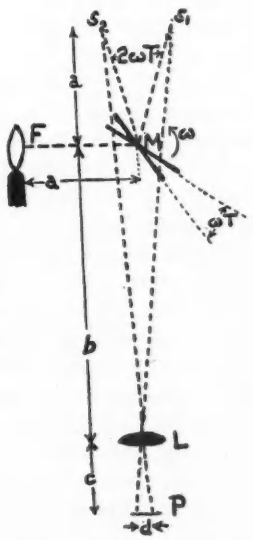

FIG. 4. Drawing representing the images s_1 and s_2 of the flames in the rotating mirror and their images on the photographic plate.

[8] Photographs of manometric flames have been published by Austin, *Physical Rev.* 12, 121 (1901); and of vibrating flames, by Marbe and Seddig, *Ann. d. Physik* 30, 579 (1909).

The apparatus which he used is shown in Fig. 8. Koenig states:[4]

> A particular apparatus, which I construct for the observation of interference-phenomena of the most various kinds, is founded on the method first employed by Herschel, and after him by many natural philosophers. This is to produce interference by permitting the waves from the same source to traverse two courses differing in length by half a wave, and then to reunite them. It consists of a tube that between its ends branches into two arms, one of which can by drawing out be lengthened at will. If we wish a complete interference, we must introduce a simple note into the tube, which is joined to a resonator, before which we sound the proper tuning-fork. If we now lengthen the one arm until the difference of length of the two is equal to half the wave-length of the note of the tuning-fork, the waves coming from the two arms are mutually destroyed at the other end of the tube; and if we fix this into a small cavity, over which a mamometric capsule is placed, we see, on drawing out one of the arms of the tube, how the at first deeply serrated flame-series in the rotating mirror gradually transforms itself into a band of light until the difference of a half wave-length is attained.

In duplicating this experiment we produced the sound by blowing air across the mouth of one of the resonators connected to the interference apparatus and observed the pattern in the rotating mirror as one arm was lengthened. The interference position could be repeated within about 1 percent, and the frequency of the resonator, obtained from the measurement of the displacement of the arm, checked the resonator frequency within a few percent. It was found that the interference position could not be checked quite so accurately with the microphone and oscillograph. In this case it was difficult to say exactly when the oscillograph trace became straight, for there was always a small amount of sound entering the microphone from the source, even though the source was well soundproofed.

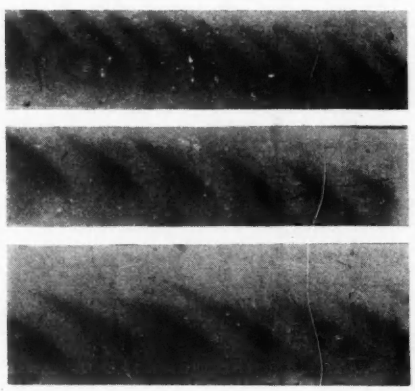

FIG. 5. Photographs of the manometric flame images of notes having frequencies of (*a*) 256 and (*b*) 384 vib/sec; (*c*) is the resultant of the two notes.

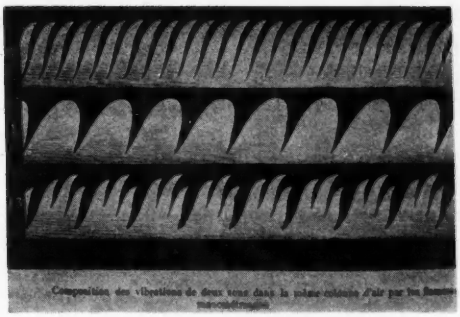

FIG. 6. Koenig's drawing of the composition of two sounds.

Koenig's explanation of the mechanism of the manometric flame was that the flame went up and down with the compressions and rarefactions in the sound wave. This does not appear to be correct. Our photographs show not only the increase and decrease of luminosity of the flame with the compressions and rarefactions but also that the increase in luminosity from a given compression may last during one or two vibrations. This suggests that a compression increases the luminosity of a small portion of the gas at the base of the flame and this luminosity travels up the gas with a finite speed. The drawing of Fig. 9 represents this phenomenon. A compression increases the luminosity of a small region at position a corresponding to the position a' of the image of the flame in the rotating mirror. After a time T of one period, when the next compression arrives at the flame, the luminous portion has traveled to b in the flame corresponding to the position b' in the image. Similarly, in another period T the luminous portion travels to c. Thus the time the luminous portion takes to travel up the flame may be determined. By measuring the height of the flame and knowing the time taken to travel this distance, one can measure the speed of a flame in the gas. This speed, which depends on the composition of the gas, is of the order of 400 cm/sec.

In order to have a check on this explanation of the manometric flame we decided to view the flame stroboscopically. Accordingly, a stroboscope disk was made about 1 ft in radius and having 36 slots near the perpihery. It was driven by a Cenco rotator. The appearance of the flame through the stroboscope was striking, for at suitable speeds the luminous portions, such as *a*, *b* or *c* in Fig. 9, appeared to be at rest. Since it was not possible to keep the speed of the stroboscope exactly constant, it was only for short periods that the luminous portions could be made to appear stationary. Generally they seemed to move slowly up or down and when moving down gave the appearance of a drop of water slowly issuing from a nozzle. Using a note of 384 vib/sec, we photographed the images in the rotating mirror (Fig. 10).[9] The same images in the rotating mirror were then photographed through the rotating stroboscope adjusted to the speed necessary to hold the luminous portions at rest. These are shown in Fig. 10 (*a*) and (*b*). Finally, the flame was photographed directly through the rotating stroboscope [Fig. 10(*c*)]. The pictures show clearly the existence of the luminous portions.

As a check on the speed of rotation of the stroboscope the frequency of the 60-cycle alternating current was determined by using a 2-w

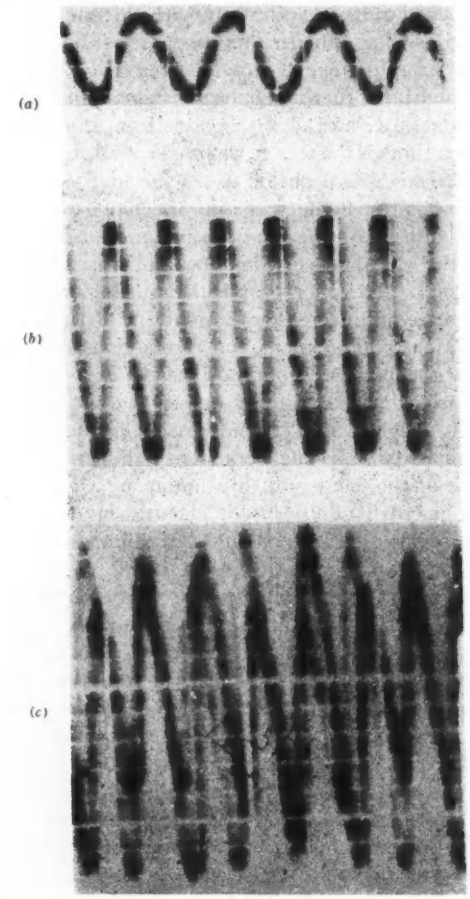

FIG. 7. Oscillograph records of notes having frequencies of 256 and 384 vib/sec taken separately, (*a*) and (*b*), and together, (*c*).

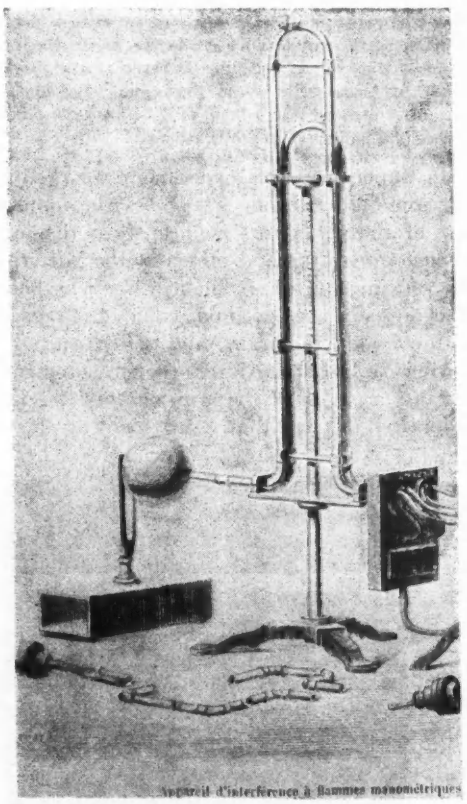

FIG. 8. Koenig's drawing of his interference apparatus.

[9] Photographs of a manometric flame viewed through a stroboscope disk have been made by E. G. Richardson, *Proc. Physical Soc. London* **35**, 47 (1922–23).

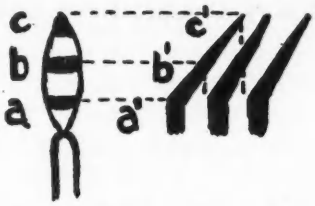

FIG. 9. Drawing showing luminous portions of a manometric flame.

neon lamp as the source of light. This is an interesting experiment for the physics student to perform, for it clearly brings out the usefulness of the stroboscope. With the speed correctly adjusted, the luminous portion of either half of the electrodes of the neon light can be made to remain stationary.

For lecture room demonstrations as well as for purposes of investigation it appears that the microphone-oscillograph combination is much superior to the manometric flame for analysis of sound. But in interference experiments the manometric flame was the more accurate of the two to use. An approximate value was determined for the speed of the luminous portions in the gas of the manometric flame. This flame obtains the oxygen necessary for its combustion

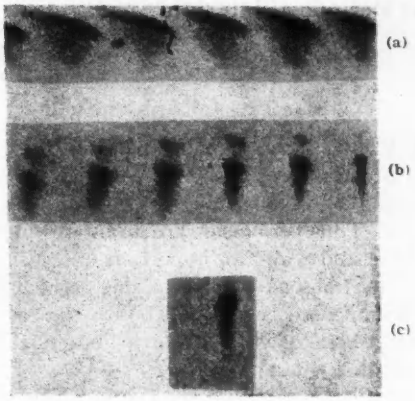

FIG. 10. Photographs of the image of the flame looking: (*a*) in the rotating mirror; (*b*) through the stroboscope with rotating mirror; (*c*) through the stroboscope without rotating mirror.

by diffusion of the air into the flame. Such a flame is known as a *diffusion flame* and is in contrast to the type of flame that occurs in an inflammable mixture such as exists in a gasoline engine cylinder.

The authors wish to thank Professor A. T. Jones for reading this manuscript and for his helpful suggestions.

[*In his Friday evening lectures at the Royal Institution, Sir James Dewar*] *never failed to grip his audience, not by his eloquence nor by the clearness of his exposition—actually he was difficult to follow—but by the extraordinary display he made of experimental illustrations which fascinated by their elegance and originality. Faraday took pains, but he handled simpler themes. Dewar took more pains. The stock illustrations made no appeal to him, but he developed lecture-demonstration to a fine art. In the course of 60 years I have listened to all the great lecturers on Friday evenings—others may have told their story more clearly, more convincingly; but no one has ever approached him in the calculated perfection of his illustrations. He regarded the lecture as an artistic performance, to be staged with absolute forethought and utmost care, provided with original scenery and all necessary appointments, without count of cost. He had the same ambition in the Royal Institution lectures that his friend Irving, the great actor, had on the Lyceum stage. The accounts on record give but the faintest idea of the performances we witnessed.*—H. E. ARMSTRONG, *J. Chem. Soc.* (England), 1928, p. 1070.

The Periodical Literature of Physics: Some of Its History, Characteristics and Trends

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PERIODICALS provide the living literature of physics—the source material in which unfolds continually the true history of the science. Thus periodicals are an interesting subject for study, and an important one just now, since they present some perplexing problems that need immediate solution. To say that we are facing a breakdown in research library facilities is not an exaggeration.

Some Early History[1]

A little before the middle of the seventeenth century, booksellers began to send out, at regular intervals, catalogs of books which they tried to make more attractive by including short descriptions of each book listed. Soon these little commentaries, or notices, became the leading feature of the catalogs. These annotated catalogs, begun in 1646, are credited with being the first periodicals. Of course, they were not in the wider, modern sense periodicals or journals.

Some 19 years elapsed before the next step in the history of such publications. In France, in this period, there was a scholar named Denys de Sallo, who was an avid reader and who employed copyists to transcribe passages of particular interest to him. This material he arranged so that he could quickly obtain information on all sorts of subjects. It occurred to him that he might do this kind of thing for the public, and so he devised the scheme of publishing weekly accounts of general interest. Thus was founded the *Journal des Sçavans*, issued for the first time on January 1, 1665. It was the first journal, in the modern sense.

Since part of de Sallo's plan was to publish lists and summaries of books, it is probable that he got some of his ideas from the book catalogs which had been begun 19 years earlier. But in the first number of the *Journal*, de Sallo wrote that there would also be accounts of experiments in physical science, of curious inventions of mathematicians, of events in the world of letters, obituaries of famous men, and so on. Previous to de Sallo's time, scientific communication was by private correspondence, which was unreliable, often being local in character and colored too much by personal opinion. Thus his conception of a journal and, especially, its actual publication, are important events indeed in the history of scientific development.

Although de Sallo was the first actually to get out a journal, others had been entertaining similar ideas. Some three years earlier, the Royal Society of London had formally come into existence. Almost immediately its members—notably Hooke—were talking about the need for a regular publication. However, nothing more was done until 1665, when Henry Oldenburg, then secretary of the Society, decided to begin a journal as a private venture.

The Council of the Royal Society gave Oldenburg its blessing by granting a license for the journal, to be called the *Philosophical Transactions* of the Royal Society. It was specified that each issue should first be reviewed by some members of the Council. On March 6, 1665, two months after the appearance of the French *Journal*, Oldenburg put out his first issue. This was the first journal to be sponsored by a scientific society. It and the French *Journal* were the patterns for all subsequent periodicals—the *Transactions*, with its emphasis on experimental knowledge, becoming the model for publications of scientific societies; and the *Journal*, being more popular and literary, the model for magazines intended for the general reader.

In the first issue of the *Transactions*, Oldenburg wrote a dedication to the Royal Society that began as follows:

> To the Royal Society. . . . In these rude collections, which are only the gleanings of my private diversions in broken hours. . . .

[1] Based mainly on M. Ornstein, *The role of scientific societies in the seventeenth century* (Univ. of Chicago Press, ed. 3, 1938); A. Wolf, *A history of science, technology and philosophy in the 16th and 17th centuries* (George Allen and Unwin, 1935); A. Wolf, *A history of science, . . . in the 18th century* (Macmillan, 1939); C. T. H. Wright, "Periodicals," *Encyclopedia Britannica* (ed. 14); L. N. Richardson, *A history of early American magazines*, 1741–1789 (Nelson, 1931); F. L. Mott, *A history of American magazines* (Harvard Univ. Press), 3 vol.

All who have had the experience of trying to develop a journal for a new and struggling society will know exactly what Oldenburg meant back there in 1665 when he wrote of rude collections gleaned in broken hours. It is said that during his life, in which he put out 12 volumes of the *Transactions*, his profits from the journal never exceeded four pounds per year. Oldenburg, if he could return today, would of course be amazed if not terrified by scientific progress; but so far as the physics journals are concerned, he would feel at home.

Beginning with its first issues, the *Transactions* published types of material that would seem quite modern to readers of today. Moreover, it soon began to publish original papers. Boyle and Newton were contributors in the early years. About this same time, Huygens, Mariotte, Roberval, Leibniz and others were contributing to the French *Journal*. Mention is made of this fact about original papers because at least one historian has credited a later, popular journal with having initiated the practice, in 1682, of publishing original contributions in periodicals. But it seems clear that both the *Philosophical Transactions* and the *Journal* had anticipated this idea by at least ten years. Indeed, as the following list indicates, scientists played a major role in creating the periodical and making it a medium for quick transmission of current information and researches, and also a forum for world-wide opinion.

Some Significant Events

1600(ca.)	First informal scientific societies, Italy.
*1646**	First annotated book catalogs.
1657	First organized scientific society, Accademia del Cimento.
1662	Charter granted to the Royal Society of London.
1663	Royal Society plans an official society periodical.
1665	First real periodical, *Journal des Sçavans*.
1665	First society periodical, *Philosophical Transactions*.
1667	Leibniz begins elaborate plans for scientific societies.
1681	Single issue of the *Journal* devoted to one topic, comets.
1682	*Acta Eruditorum* founded in Leipzig.
*1682**	Lay periodicals begin to publish original articles.
*1691**	First literary periodical, *Works of the Learned*.
1702	*Journal* institutes a board of editors.
*1709**	First essay periodical, the *Tatler*.

Only those events that are marked with an asterisk were extrascientific in origin or character.

Once the *Journal* and the *Transactions* had been established, the number of periodicals began to increase rather rapidly—in England, France, Italy, Germany and Holland. Among these late seventeenth-century journals was the elaborately conceived *Acta Eruditorum*, with its articles in Latin, published monthly in Leipzig from 1682 to 1734; its effect in stimulating scientific interest in Germany was important.

In the eighteenth century, the earliest periodicals in the British Colonies of America gave little attention to the sciences. Apparently the first person to conceive of the publication of a true magazine in the Colonies was Benjamin Franklin, in 1740. But it was not until 1769 that any scientific articles of merit began to appear, in Lewis Nicola's *The American Magazine, or General Repository*, which also contained during its first two years a separately paged department, "The Transactions of the American Philosophical Society."

Russia in 1775 acquired its first periodical of any kind, founded by the Russian Academy of Science. Elsewhere, near the end of the century, were founded various journals that were to have an important role in the history of the physical sciences; notably, *Annales de Physique* (1789), *Nicholson's Journal* (1797), the *Philosophical Magazine* (1789), and L. W. Gilbert's *Annalen der Physik* (1799). The "Phil. Mag.," because of its high quality and distinctly international outlook, was of special significance in periodical history.

In the nineteenth century the expansion was rapid. By 1863 the number of scientific journals and various proceedings of scientific societies exceeded 1500; and in another ten years it had grown to more than 2000.[2] Among the important physical journals started in the first half of the century were *Mémoires de Physique et de Chimie de la Société d'Arcueil* (1807), Sweigger's *Journal*

[2] These figures are estimated from the listings in the *Catalogue of scientific papers*, 1800–1863, 1864–1873 (C. S. Clay, 1867–79), vols. I–VIII. The tremendous task of compiling this valuable *Catalogue* of titles, authors and dates of scientific papers published since 1800 was carried out by the Royal Society of London as the result of a suggestion made to the British Association in 1855 by Joseph Henry.

für Chemie und Physik (1811), and *Comptes Rendus* (1835). In 1824 the editorship of the *Annalen der Physik* was assumed by J. C. Poggendorff, who continued with it for 50 years, never accepting a professorship so that he might devote all of his time to editing and research. Under his guidance, the *Annalen* became the foremost scientific journal in Europe.

In the United States the first scientific journal of importance was the *American Journal of Science*, popularly called "Silliman's Journal." It was started in 1818 and exerted great influence. A number of notable physical papers appeared in it; for instance, 11 contributions by Henry, including his famous paper of 1832 on self-induction, and, much later, of course, some of Gibbs' and Rowland's papers. Also started in this period was the *Journal of the Franklin Institute* (1828).

Courtesy of Yale University Art Gallery

Benjamin Silliman, 1799–1864, from the painting by the American artist and inventor, Samuel F. B. Morse. It was while studying under Silliman and Jeremiah Day of Yale College that Morse became interested in electricity.

One paper that American editors missed publishing—in fact, rejected—was Rowland's first paper, which announced his discovery of the magnetic circuit and put the whole subject of magnetism on its feet. Rowland finally sent the manuscript to Maxwell, who recognized its quality and immediately had it published in the *Philosophical Magazine*. Maxwell felt that it had been held up long enough, and read the proof himself so that it might be rushed through.[3]

This is not the only time, of course, that editors of physical journals have slipped up in their judgment of a paper. The classic example probably is the rejection of J. R. Mayer's first paper on conservation of energy by Poggendorff's *Annalen*. In defense of Poggendorff it must be said that Mayer was unfamiliar with physical terminology, and that he wrote incomprehensibly and betrayed a certain ignorance of the physics of his day. Poggendorff may have thought that the paper was the work of a "crank," of the sort that editors are continually receiving and that often end up by being privately printed. Yet the lesson for editors of scientific journals is that no paper should be rejected carelessly.

Rowland's excellent paper was rejected because the editors in this country apparently could not comprehend it. This was shortly after 1870, when advanced physics was not yet being taught in American colleges. Practically all the good physicists of the time received their advanced training abroad, and probably depended mostly on journals published outside the country. It is understandable why it was not until 1893 that the *Physical Review* was founded, and why for a number of years it was far from being one of the leading journals of physics.

Even a slight knowledge of the history of periodicals may be helpful in understanding some problems presented by periodicals today, and this is the only excuse for giving a historical account that is sketchy and for most purposes inadequate. If nothing has been said about the attributes and quality of the articles in the early journals, it is partly because most readers are already familiar with them, through the files of the older journals, the collected works of individual physicists and numerous other collections of original memoirs.[4]

Early technical writing naturally differed little from ordinary expository discourse; but gradually our archive literature has acquired distinctive characteristics, and now the best of it is so efficient in performing its peculiar functions as to be regarded as a definite, major type of written communication.[5] Although serious deficiencies

[3] H. F. Reid, "A great American physicist—Henry Augustus Rowland," *Am. J. Physics* 9, 117 (1941).

[4] For instance, *Harper's scientific memoirs*, Ostwald's *Klassiker der Exakten Wissenshaften* (Engelmann, Leipzig) and W. F. Magie's *A source book in physics* (McGraw-Hill, 1935). Many important papers, especially those published during the last 50 years, have not been reprinted, and this should be done.

[5] Some characteristics of modern archive articles and the reasons for their functional excellence are outlined in my article on technical writing and editing, *Am. J. Physics* 13, 99 (1945).

still remain—poor terminology, noninternational conventions, lack of methods for conveying certain meanings with sufficient refinement—nevertheless, the models of technical writing that can be set up today are unique and elegant. One eventual result will be an improvement in the quality of ordinary expository writing, thus tending to reverse the historical development. Ordinary exposition will come to be a modification of the technical, rather than the other way around.

Types of Articles and Reports

Although archive articles are the kind most peculiar to a science, they are not the only type that physicists have to write. The main types evidently are:

Archive material: research articles and notes; abstracts.
Progress and summary reports to research directors.
Survey or summary articles for specialists and near-specialists.
Borderline articles addressed to physicists: history; philosophy; socio-economic aspects; teaching.
Ephemera: editorials; accounts of meetings; news items.
Student laboratory reports.
Survey articles for scientists other than physicists.
Reports of research directed to nontechnical administrators.
Popular articles: for educated laymen; for people in general.

The several types are here listed roughly in descending order of technicality. At the top is the purely archive material, designed for highly trained and very homogeneous groups of readers. At the bottom, the readers form the largest and most heterogeneous group. In going from top to bottom the effective writing technics and functions of the language gradually change, until we have traversed the whole linguistic scale and reached the opposite pole.

Getting close to the opposite linguistic pole is important if the people are to be reached effectively; and many present authors of so-called popular science articles lack the kind of creative ability needed to do it. Nor is this a job for the gifted scientist, not because it is beneath him, but because, as Ivan Pavlow once told his students, if a scientist had two lives, they would not suffice for his own work. As was said in another place,[5] the scientist has been criticized for failing to put his knowledge and methods into such form that they can be effectively assimilated into our modern culture. But it is possible that his responsibilities are misunderstood. Two of his jobs obviously are to make the real advances in science itself and to train the next generation of scientists—jobs that no one else can do. It is in a third, and final, professional responsibility that the physicist, especially, seems to have failed. This is in trying wholeheartedly to participate in the general training of those able students of the social studies, the humanities and the fine arts whose mental and creative abilities are comparable to those of the gifted scientist himself. Here is a social responsibility and challenge for even the most gifted of physicists.

As for reaching the people in general, this is a lifetime job in itself. Before the scientific outlook can become really functional—affecting the behavior of the great mass of people—its human and emotional significance must be formulated and imparted to them; and this is not primarily the task of the sciences but of creative literature and art. To paraphrase something said by R. W. Emerson: A Raphael must paint the wisdom of science, a Handel sing it, a Phidias carve it, a Shakespeare write it, a Wren build it, a Luther preach it. If we can reach the capable artists, the statesmen, the creative writers of our age, they will reach the people.

Present-Day Problems Concerning Periodicals

Seventeenth-century periodicals already were publishing about the same types of material that we publish today—original research, news of discoveries, correspondence, book reviews, and so on. Nor have there been many innovations in the editing of manuscripts; physics editors still carry on their work as avocations—like Oldenburg, in their "broken hours." Other procedures, such as boards of editors and referees for papers, also seem to have been adopted very early.

Naturally there have been marked improvements in printing and illustrating, and in quick delivery of copies to subscribers. The number of journals in physics has increased, and for the eight American journals, a decided improvement has been the centralization of the business management and part of the editorial mechanics in one agency—the American Institute of Physics.

These are some of the changes in our periodicals through the years. But what are the changing

conditions that must be met? *First*, tremendous increases in rates of physical research and activity, with comparable increases in the amount of material to be collected, edited, published and read; *second*, a marked increase in the diversity of interests and places of occupation of physicists; *third*, as indicated earlier, a possibility greater than ever before of making technical writing and editing highly developed arts.

Thus, while we have made changes and improvements in methods of disseminating new knowledge, they appear to be small when compared with modern scientific and professional demands. In some fields periodical editing and publishing already have passed out of the merely avocational stage and are in the hands of corps of experts. In physics these experts must continue to be physicists who have a primary and creative interest in all aspects of technical editing and writing. Moreover, their editorial assistants must have something more behind them than a couple of courses in English composition; inserting commas and checking spellings will be a negligible part of their duties.

Of all publication problems, however, the most perplexing are those arising from the enormous extent and diversity of our current literature. An issue of any physics journal devoted exclusively to archive material necessarily is much like a package of fairly unrelated reprints, the main differences being that the reprints are bound together and that a table of contents and, periodically, an index are furnished. Unlike the old days, it is now impossible for physicists in any appreciable number to read, for profit or fun, the whole assortment of articles in each of the many "packages" that continually come to them, and that are pouring into libraries. For one thing, nearly every article necessarily begins where several articles in preceding packages left off; and a goodly number of these continued articles have been running for years, with the various installments often appearing in different journals and different languages.

As for the time needed for reading, everyone well knows that the literature of even a small area of research may now be so voluminous that even the specialist cannot keep up with all of it. If he did, he would be in the same fix as the graduate student who could never turn out research because every day it took him all day to polish up his apparatus and get ready for a run, and then it was time to go home.

Another problem is where to get the money to purchase and bind periodicals, and where to put them after they are bound. We have already reached the point where only large and wealthy laboratories can afford to have anything approaching complete periodical files. The mere storage problem is formidable. For the 24-year period ending in 1938, the bound volumes of just one journal, the *Philosophical Magazine*, occupy some 5 yd of shelf space. For the bound volumes of the *Physical Review*, *Philosophical Magazine* and *Science Abstracts A*, about four times as much shelf space is needed for the last eight years of the 24-year period, as for the first eight years. The growth shown in the *Physical Review* occurred, despite the fact that during this period seven other physics journals were started in this country, not to mention dozens of borderline journals that helped to relieve the pressure. Since more will be said later about abstract journals, it is of interest to note here that *Science Abstracts A* for the 24-year period occupies only about one-third of the shelf space needed for one of the other journals.

To get some idea of what we face in physics, consider the situation in chemistry, with 3700 periodicals listed by *Chemical Abstracts* as worth watching for possible articles[6]; or in biology, with an estimate for the year 1936 that annually 70,000 papers were being published in 6000 journals and 30 languages.[7]

> These figures give but a rough approximation of the magnitude of the scholar's task in keeping informed of the research being carried on and published in the biological field. Scarcely any library in the world is so organized and so financed that it can be even reasonably complete. When we consider that the library of the Marine Biological Laboratory at Woods Hole contains about 2300 periodicals, and the library of the Academy of Natural Sciences in Philadelphia (including geography, mathematics, physics and chemistry, as well as biology) contains about 2500 journals, we gain some conception of the difficulties which have been imposed upon librarians and scholars through the tremendous multiplication of periodicals in which research in the biological sciences is published.

[6] *Supplement to the list of periodicals abstracted by Chemical Abstracts* (1942), p. i.
[7] *Biological Abstracts*, "Report for 1944," p. 8.

A recent book on the future of the research library points out that, for over three centuries, the great libraries have been doubling in size every 16 years. For example, should the library of Yale continue to grow at the rate at which it has grown for over two centuries, it will, a century hence, have approximately 200,000,000 volumes and will require a cataloging staff alone of over 5000 persons.[8]

One authority among librarians has said that the research library situation is so critical that some kind of action should be taken, not in a matter of years, or of months, but of weeks.

Microphotographic Reproduction of Archive Articles

Physicists should be among the first to see that microphotographic reproduction of archive articles may provide the only satisfactory solution to this problem. A whole issue of one of our present journals could be put on a couple of 3×5-in. *micro-cards*. A whole periodical library would occupy about the same space as our present card catalogs.

There have been two main obstacles to microphotographic reproduction. One is the absence of adequate reading machines at the right price, but apparently this will be removed with quantity production. One estimate for quantity production is as little as ten dollars per unit; and if this is correct, such devices would soon be more common than typewriters. A second obstacle has been the lack of adequate means for indexing and reference, and this is being studied.[9]

One possible scheme for handling physics archive articles will be outlined, merely because it is typical of various procedures that should receive immediate and serious consideration. The proposal is that all physics journals in the future publish, not the complete research articles, but high-grade abstracts, or digests, of these articles, and also original notes of the "Letter to the Editor" type, brief summaries of current researches similar in character to those now appearing in *Nature*, and news about the society or other agency that sponsors the particular journal in question.

An author would send his manuscript in the usual way to the editor of the journal, who would have it checked by referees and then edited. At the same time the abstract would be carefully edited and promptly published in the journal. Finally, a master copy of the complete, edited paper would be made and photographed, and the negative and master copy filed in some suitable place—perhaps in the society office, or the American Institute of Physics, or the American Documentation Institute in Washington. Readers of the journals could obtain a micro-print of any complete article by sending an order to the central agency; or a standing order could be placed to receive micro-prints of all articles, or conceivably of all articles in a certain restricted field.[10]

Admittedly it is much easier to outline a scheme such as this than to study all possible plans and put their best features into operation. Many vexing questions doubtless would arise, but this should not stump physical scientists—the ones who made microphotography possible. This kind of reproduction may well turn out to be one of the most significant advances since Gutenberg. Study of its possibilities is a small job if one considers the time and energy wasted by only a few research workers who needlessly duplicate existing results merely because of inadequate library facilities.

It is to be emphasized that these remarks on microphotographic reproduction pertain solely to detailed research articles. Printed periodicals would still be used for abstracts, surveys of research, bibliographies and research news. Indeed, printed survey articles are now almost indispensable, even with our present system of publication.

These survey articles are of two types. One is for the specialist, of the kind usually published in *Reviews of Modern Physics*. The other type is intended for physicists in general. Although college teachers, especially, need general articles, this task of keeping all physicists informed of

[8] Reference 7, p. 9.

[9] See, especially, F. Rider, *The scholar and the future of the research library* (Hadham Press, 1944).

[10] This plan does not differ essentially from the one for a microfilm service developed and put into operation more than a decade ago by Watson Davis for the Documentation Division of Science Service, 1719 N Street, NW, Washington 6, D. C. Thus there is already available a service that could be used, for instance, in recording and distributing the great mass of war research literature, with much saving of time and money. For a recent description of auxiliary publication by microfilm, see W. Davis, *Saturday Rev. Literature* (June 9, 1945); also, reference 9.

trends in the science as a whole has another important function: it will help retard the natural tendency for the science to split up into isolated research areas—areas that can grow so far apart that workers in different groups hardly speak the same language.

Abstracts

As soon as microphotographic reproduction is adopted for archive articles, abstracts of high quality will become indispensable. But even with our present system of publication, the situation with regard to abstracts needs more attention than it has been given.

The quality of abstracts has improved through the years, much of this doubtless owing to the somewhat unappreciated efforts of Gordon Fulcher, who developed the idea of so-called "analytic abstracts" and set a standard for abstracting that is high.[11] As Doctor Fulcher has pointed out, an abstract that is sketchy, incomplete and unreliable is worse than useless. It should not be a mere description of the contents of an article, but should give essential results—even very important graphs and tables of data, perhaps abridged—and significant details, such as special apparatus and processes.

An abstract prepared by the author of the paper is valuable because he knows the points in his work that should be stressed. But most authors do not pretend to be expert abstractors, and their versions could be greatly improved by the staff of the abstract journal. Fewer readers would then have to consult complete articles. Moreover, a skilfully prepared abstract makes "good reading," being a sort of miniature survey, although of one piece of research rather than of many. If abstracts were of this character, the various societies might be more amenable to the proposal that their archive journals be converted to high grade abstract, or digest, journals, in the event that microphotography is used for the complete research articles.

An International Abstract Journal

Regardless of whether archive journals eventually confine themselves to abstracts, it still will be desirable to have an abstract journal of international scope, somewhat similar to the present *Physics Abstracts*. If correctly conceived, it would be the only physics abstract journal that libraries would have to bind.

One ideal for this international abstract journal clearly should be to cover every technical periodical in the world, including those in borderline fields, that prints material of possible value to the research physicist. The present *Physics Abstracts* has made some progress in coverage. In 1907 it listed approximately 200 periodicals as covered, or occasionally covered; by 1938, this number had risen from 200 to 300. But when this number is compared with, say, the 3700 periodicals listed by *Chemical Abstracts*, the indication is that we still are some distance from a total coverage in physics. Another feature of the world abstract journal evidently should be a carefully prepared analytic index, and not merely a list of titles of papers.[12]

Finally, immediate study should be made of the advisability of adopting a secondary, world language for use in the international abstract journal, so that the essential results of research will be readily available to the workers of all nations. At the start it is only fair to give warning that anyone who supports such a proposal is likely to find himself classed "with those earnest creatures who are eager to redeem the world through a diet of raw carrots or by dividing the solar year into ten months of ten days each."[13] Nevertheless, a good many eminent names, going back as far as Leibniz, have been associated with the subject. "If a cause were to be judged by the quality of its general staff, the international language movement should command respect."[13]

It is doubtful if anyone who has studied the matter will say that an *auxiliary* language is not needed. The point on which opinion differs is whether this language should be: an artificial language, such as Esperanto; or a "dead" language, such as Latin; or a modern language. Each has both advantages and disadvantages, but to discuss them adequately and fairly would

[11] G. Fulcher, "Scientific abstracting," *Science* **54**, 291 (1921); reprinted as No. 21 in the Reprint and Circular Series of the National Research Council.

[12] The need for improved abstracting, indexing and translating services on an international scale is emphasized in the OSRD report, *Science—the endless frontier* (Government Printing Office, 1945), esp. pp. 112–115.

[13] A. Guerard, "International language and national cultures," *Am. Scholar* **10**, 170 (1941).

require considerable space. Moreover, it is questionable whether such discussion would be of practical value here, for what are the chances that scientists will in the near future consider adopting an artificial or dead language for, say, their chief abstract journal? This seems to leave a modern, living language as the only immediate practical possibility.

As to what this language should be, the indication is that most of those favoring a living language at all think that it should be English. This opinion is not confined to English-speaking peoples. If it were, we would be in the position described by the Frenchman, who said that a man who tried to talk another language is always in danger of making a fool of himself, and that the Englishman always prefers the other fellow to be the fool.[14]

A first step in making English the auxiliary language of physics consists merely in having an abstract journal in English that is so complete in coverage and so high in quality that all the physical scientists of the world will find it indispensable. A next step is to have the abstracts written in *simple* English, which is usually the best English.

Now, different authors would have different ideas of what constitutes simplicity, and hence there would soon be a need for a definite code for simplification. Various schemes have been proposed by linguists. One, for instance, involves the use of some system of phonetic spellings, for it is generally acknowledged that our present spellings are absurdly complex, often being based on mere chance, whimsicality and affectation.[15] Surely English spellings eventually will undergo some systematic and drastic reforms, and scientists should be among the first to support them. But the chance that physicists today would be willing to adopt phonetic spellings for an abstract journal seems small, and what is wanted is a method that can be adopted immediately.

The quickest and perhaps most practicable way to simplify English is to use a restricted vocabulary, upon which all authors and readers throughout the world could rely. Obviously such a vocabulary should be set up by experts in linguistics and should be suitable for use in other fields as well, and it was such considerations that led me to suggest[16] the adoption for abstracts of a vocabulary already in existence—that of Basic English. The fact that the 850 words in the Basic general vocabulary are supplemented with several hundred Basic words for physical science and mathematics evidently was overlooked by the commentator[17] who proposed the following test prefaced by the comment, "We should like to know how this paragraph would appear in scientific Basic English acceptable to Frenchmen, Chinese, Germans and Japanese."

> If preliminary tests have shown the presence of non-volatile organic compounds or oxalic acid, the filtrate from the hydrogen sulphide precipitate is evaporated to dryness with concentrated nitric acid and the residue slowly ignited until no more tarry-smelling fumes are evolved. The residue is then digested with concentrated hydrochloric acid and boiled. Phosphoric acid is then tested for with ammonium molybdate solution. Phosphoric acid is removed by evaporation of the hydrochloric acid-free solution with concentrated nitric acid after the addition of metallic tin in the form of tin foil or else of granulated tin.

An answer to the test follows:

> If, in the first tests, it has been noted that oxalic acid ($CO_2HCO_2H \cdot 2H_2O$) or other nonboiling organic compounds are present, the solution filtered from the hydrogen sulphide (H_2S) deposit is dried by evaporation with a concentration of nitric acid (HNO_3), and the resulting deposit is slowly burned till no more fumes come off. The residue is put through a digestion process with a concentration of hydrochloric acid (HCl) and is then boiled. A test for phosphoric acid (H_3PO_4) is then made with a solution of ammonium hydroxide (NH_4OH) and molybdic acid (H_2MoO_4). If phosphoric acid (H_3PO_4) is present, it is taken out by evaporation of the hydrochloric acid-free solution with a concentration of nitric acid after the addition of tin rolled thin or in the form of grains.

The writer quoted may also have been unaware of the fact that it is permissible in writing Basic English to introduce any word desired, the only requirement being that one first define the word in terms of Basic words.

The objection is sure to be raised that simplification of the English in the international abstract journal is unnecessary, since every alien physicist

[14] R. E. Zachrisson, *World English in easy spelling* (Uppsala, 1930).
[15] Reference 14; also, J. W. Hamilton, *World English* (1928).
[16] *Science* **101**, 299 (1945); reference 5, p. 101.
[17] *New York Times*, Mar. 29, 1945.

will be an educated person, able to use full English with facility. This will not necessarily be true in the future, because of the enormous increase in numbers of workers *of all grades* and because so many of these workers will be trained at home. It is not that the number of people in the world having some knowledge of English will decrease; this number is increasing all the time. The danger lies in the fact that, along with this increase in numbers, there will be a marked reduction in the average knowledge of full English possessed by these people; and it is a phenomenon well known to linguists that when large numbers of people of alien traditions use a language of which they have only a slight knowledge, this language begins to disintegrate.[18] As an extreme example, in some Eastern countries English is rapidly degenerating into dialects among people having only a slight knowledge of it.

Thus there is a considerable difference between a slight knowledge of complicated English and a full knowledge of systematically simplified English. If physicists would take the lead in adopting simplified English as an auxiliary language, they could make a cultural contribution of great significance. The change to Basic English in the world abstract journal could be made in a matter of a few months' time, and it is safe to say that the majority of American and British physicists would be no more than mildly aware of the change. Nor would physicists in general have to write in Basic English, even though it is easy to learn. The staff of the international abstract journal would perform this simple task.

Despite these facts, objection to the adoption of Basic English for international abstracts may turn out to be widespread. So it should be remembered that the proposed abstract journal has other important features not connected with the question of whether a special system of English is to be used. Even a conscious attempt to use relatively simple English would be a great improvement.[19]

* * *

The main proposals made here as worthy of study are: microphotographic reproduction of archive articles; a more comprehensive program of survey articles; improvement in and wider use of abstracts; and an international abstract journal affording complete and prompt coverage and, preferably, employing an international auxiliary language. The cost of such a publication program to subscribers might turn out to be surprisingly small and, in any event, would be negligible compared with the cost of the research giving rise to the knowledge disseminated. Moreover, except for the microphotographic reproduction, any one of the proposals could be put into effect independently of the others, a fact that needs emphasis whenever there is a tendency to reject all proposals for change because some of them lack appeal or seem to be impracticable.

If the situation with regard to research library facilities really is as critical as it appears to be, then physicists, as members of various societies, should insist on an intensive and objective study of all possible proposals and, especially, immediate action in putting the most promising ones into effect. No one need be told that various current proposals already are well known and from time to time have even received some consideration. The need is for assurance that our most pressing literature problems are on the way to being solved and soon will cease to exist.

[18] Some linguists regard this tendency toward disintegration as evidence of the undesirability of adopting a living language for international purposes. But it may also be argued that the number of people over the world with only a slight knowledge of English will increase in any event, so that some form of simplified English is essential if standard English is to retain its purity.

[19] Various schemes and guides for writing simple English should be examined in this connection; see, for instance R. Flesch, *The art of plain talk* (Harper, 1946).

IT is my carefully considered opinion that very few of the articles published in technical journals are ever read, even by scientists, with interest or with great care, except by the authors themselves and some of their very close friends and associates—and the authors' students, of course.—WENDELL JOHNSON, *People in quandries* (Harper, 1946), p. 279.

Energy Transformations and the Conservation of Mass

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THE mass-energy relation $E=mc^2$, first stated by Einstein more than 40 years ago, has suddenly become familiar to almost all informed readers. There is reason to believe, however, that it is often accepted as a mystic formula rather than as an understandable relation, and that all too frequently it is completely misunderstood. This should be a matter of concern to teachers, and to everyone who ventures to interpret for the public modern ideas concerning nuclear energy. The following approach to this question, placing the emphasis upon the similarity between nuclear and molecular reactions, has seemed to provide a fairly convincing introduction for beginning students in modern physics.

There are good reasons for believing that the mass m_v of any body increases with its velocity v in accordance with the relation

$$m_v=\frac{m_0}{[1-(v^2/c^2)]^{\frac{1}{2}}},$$

where m_0 is the rest mass and c is the velocity of light. This equation may be written in a different, but exactly equivalent, form,

$$\int f\mathrm{d}s=\Delta E=m_vc^2-m_0c^2=\Delta mc^2,$$

where $f=(\mathrm{d}/\mathrm{d}t)mv$ and ΔE is the kinetic energy, that is, the energy increment representing the work done in producing motion. The range of integration is from a point s_0 where v equals zero to a point s_v where v has attained its final value. The kinetic energy ΔE is equal to $\frac{1}{2}mv^2$ when, and only when, the final velocity is small and the change in mass is negligible. These relations have been directly verified by experiment for electrons up to velocities closely approaching c, and for more massive bodies in special cases. There is convincing evidence of their universality.

Gaseous hydrogen and oxygen may be mixed together in a flask without danger of reaction. If, however, a minute volume of the mixture is activated, for example, by a small spark, there results a violent detonation. This is a typical chain process. The formation of each molecule of H_2O releases more than enough energy to stimulate the reaction of neighboring molecules, according to the familiar equation

$$2H_2+O_2=2H_2O.$$

The net energy released may be measured directly as heat, and is about 58 kcal/(mole of H_2O). This is equivalent to 0.0000025 Mev, or 4×10^{-12} erg/molecule. Assuming the original reacting molecules to have been at rest, and the two water molecules to have acquired equal kinetic energies, we find the resulting velocity of each to be about 5×10^5 cm/sec, or $0.000016c$. In consequence, the mass of each water molecule will exceed the rest mass of H_2O by about 1 part in 10^{10}, an amount far below the limit of observation. In this case, therefore, the mass-energy relation fails to provide a useful means for measuring the reaction energy.

The heat of combustion has its origin, of course, in the molecular forces that bind the atoms together. Although H_2 and O_2 are stable molecules, H_2O is more stable. The work that would be required to separate completely the six atoms in two water molecules is greater than that necessary to separate the six atoms in two hydrogen molecules and one oxygen molecule. Therefore, work must be done to change water into hydrogen plus oxygen, and the reverse process releases energy.

The reaction observed in 1932 by Cockcroft and Walton is similar to this in many respects. Hydrogen ions, after being subjected to an accelerating potential of 100,000 v, were allowed to fall on a thin film of metallic lithium placed in a cloud chamber. Alpha-particle tracks of range 8.31 cm were observed. They occurred in pairs, oppositely directed, and were apparently produced by the disintegration of Be^8, which is an unstable intermediate product formed when a proton is added to a Li^7 nucleus:

$$Li^7+H^1=Be^8=He^4+He^4.$$

The proton, having been given a velocity of

$0.014c$, has sufficient energy to permit a close approach to the lithium nucleus. Its resultant increase in mass is one part in 10,000. Since the mass of Li^7 is 7.0180 amu, and that of H^1 is 1.0081 amu, the combined Be^8 atom[1] must have a mass of

$$(7.0180+1.0081+0.0001)\text{ amu}=8.0262\text{ amu}.$$

The initial velocity of a helium nucleus with a range of 8.31 cm may be found without difficulty from the velocity-range relation for alpha-particles as determined experimentally. This proves to be $v=0.068c$, from which it follows that $m_v/m_0=1.0023$. Since m_0 is 4.0039 amu for He, the value of m_v is 4.0131 amu. Thus the total mass of the two product particles as they leave the point of separation is 8.0262 amu, and the equation is exactly balanced. Kinetic energy with a mass equivalent of 17 Mev has appeared at the expense of binding energy, but no mass has been lost.

These moving particles soon come to rest because of collisions with gas molecules along the line of flight. Their energies change by many successive small decrements, and their masses diminish at the same time. Thus both the energy and the mass are dissipated by transfer to other particles, which, in consequence, have their velocities and their masses increased. The decrease in mass observed when parent and product particles are compared, does not occur at the instant of fission, but takes place subsequently. Mass has been transferred, but none has disappeared.

The explanation of the large energy release in this reaction is to be found in the intense binding forces between nucleons (protons and neutrons). Helium nuclei are very stable aggregates, much more stable than lithium nuclei. Hence four protons and four neutrons, when combined to form two helium atoms *at rest*, possess less energy and less mass than when they form one hydrogen and one lithium atom.

If a sufficiently large and a sufficiently well-determined number of these disintegrations could be produced within a calorimeter, the nuclear energy released might be measured as heat. It is much more convenient in this case, however, to determine the amount of mass that has been dissipated. Thus the net energy release may be obtained by comparing the sum of the rest masses of the final and of the original particles: $(7.0180+1.0081-2\times4.0039)$ amu $=0.0183$ amu $\equiv 17$ Mev $\equiv 39\times10^7$ kcal/mole. Since mass and energy are proportional, it is quite immaterial whether reaction energies are measured in calories, or in grams, per mole.

The nuclear fission of uranium and of other heavy atoms is a process very similar to the splitting of Be^8. An unstable nucleus divides into two nuclei of greater stability but of smaller mass; a few neutrons and some radiation may also appear. There is no change in the total number of nucleons; a large release of energy occurs, however, because in the final form the nucleons are more tightly bound, that is, their total internal energy is reduced. The difference appears as energy of motion, which, with its corresponding mass, is lost to the system only by transfer to external particles.

The dissociation of a nucleus, for example of a deuteron, requires that energy be added, and a corresponding increase in mass is observed. If the process is a photoelectric one, this mass is provided by a photon; otherwise it is contributed by the impacting particle. It is not created out of the energy. Matter may be created out of energy, as in the process of pair production, the mass of the newly created particles being supplied by the vanishing photon. Here *mass* is conserved, though *matter* is not. The same may be said of the annihilation of a positive and a negative electron, with the production of two photons.

It appears, in short, that the mass-energy relation, $E=mc^2$, is a universal rule and one of the most fundamental of physical laws. Any system exhibits mass exactly in proportion to its energy, and gains or loses mass when it gains or loses energy. While energy may be changed from one form to another, it is never changed into mass, nor is mass changed into energy. They are *not* mutually transformable. Energy may be transferred from one system to another, either with or without a change in form; mass is always transferred in the process, but is never transformed.

[1] Nuclear masses may be obtained by subtracting the mass of eight electrons from each member of the equation.

Pressure Never Has Direction

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THE purpose of this article is to clarify the meaning of *pressure*. It does not propose a new procedure for teaching the concept, but attempts, rather, to point out why certain very prevalent statements about pressure are wrong. There can be little doubt that, in simplification of material for elementary presentation, teachers and authors should avoid misconceptions which the student must later unlearn.

Pressure at a point in a fluid may be regarded as purely scalar in almost all cases that are within the scope of the usual college textbook of general physics; namely, (*a*) in any fluid at rest or (*b*) in a nonviscous fluid in any state of motion. It is not a vector quantity in any case. The writer has examined the treatment of fluid pressure in 15 textbooks, all published within the past nine years, and most of them well known. Thirteen of these books attribute vectorial properties to pressure. Even more advanced treatises are not free from the same error.

The commonest forms of objectionable statement are references to *downward* pressure on the bottom of a container, *horizontal* pressure on the sides, or pressure *normal* to a surface. If an author escapes these pitfalls, he is quite likely, in a quasi-static analysis of the siphon, to say that the pressure *toward the right* exceeds the pressure *toward the left*, and that therefore the siphon will begin to flow.

As pressure reduces to a scalar quantity in the cases in question, it is useful to compare another scalar function at a point in a fluid: temperature. It would obviously be nonsense to speak of "downward temperature." It is just as absurd to say "downward pressure." Pressure does not have direction, any more than does temperature.

A frequent expression is "pressure on the bottom of the tank." This is acceptable, if the meaning is pressure at a point at the bottom of the tank. It is wrong if the writer means pressure pushing on the bottom of the tank. The pressure is a property of the fluid at each point. Associated with the pressure, there is a force which the fluid exerts on the bottom of the tank. The pressure is not itself the force. Because of this ambiguity, it is certainly preferable to say "pressure *at* the bottom of the tank."

Many of the textbooks state that the pressure at a point is the same, or is equal, in all directions. We may perhaps charitably interpret this as an oblique and undesirable way of saying that the pressure has no direction. It is, however, quite likely that the student will infer from this expression a meaning which one book states explicitly in a footnote: "Pressure is not a vector quantity for at any point Q within the fluid it has at once any and all directions." This false notion of pressure suggests Stephen Leacock's horseman who "rode madly off in all directions." Would it make sense to say that the temperature at any point has at once any and all directions?

To understand better why the pressure at a point in a fluid does not have direction, let us consider a very simple case: a finite horizontal surface immersed in a fluid at rest. This surface will experience a normal thrust (force) which is uniformly distributed over the surface. The pressure is the thrust *per* unit area of the surface. It is not the force *on* a unit area; "per," used here with its mathematical sense, indicates a ratio, so that pressure is expressed in units of force divided by units of area.

Area may be regarded as a vector quantity, conventionally represented by an arrow drawn perpendicularly outward from the surface. As the restricted case which we are now considering does not involve motion of a viscous fluid, the force is also represented by a vector normal to the surface, and therefore parallel and opposite to the area vector. Since the two vectors are parallel, division of one by the other has no ambiguity: the pressure is the quotient that expresses the number of times the area vector is contained in the force vector. Clearly this quotient is scalar, a number without vectorial properties, but with units, force divided by area, to correlate the scales used in drawing the two vectors. The quotient is really negative, as the area vector is, by convention, drawn outward

from the surface, whereas the thrust is opposite, pressing inward against the surface. The negative sign is not written, as it is implied when we term the quotient "pressure"; a positive quotient would correspond to a tensile force per unit area.

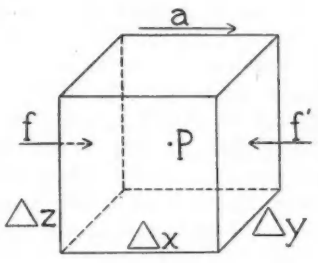

FIG. 1. Volume element of a nonviscous fluid, moving with acceleration a under the action of opposing forces f and f'.

The quotient would also be positive if we were considering the reaction to the thrust, the outward push of the surface against the fluid, per unit area.

Those who attribute direction to pressure are probably thinking of the direction of the thrust that is developed when the fluid is in contact with a surface. The pressure and the thrust are separate and distinct physical quantities. The pressure itself has no direction.

It can readily be shown that, in a fluid at rest, the thrust on a vanishingly small surface through a given point has the same magnitude, regardless of the orientation of the surface. This is the basis for the statement, previously mentioned, that the pressure at a point in a fluid is the same in all directions. But let us suppose that at the given point a nonviscous fluid is moving with acceleration, as when a liquid approaches a constriction in a pipe. Should we expect larger thrust in the direction and sense of the acceleration? Consider as momentarily rigid a small volume $\Delta x\Delta y\Delta z$ of the fluid, of density ρ (Fig. 1). Take the x-axis in the direction of the acceleration a, assumed to be horizontal. Acting on the element, of mass $\rho\Delta x\Delta y\Delta z$, there is the resultant force, $f-f'$, the difference of two thrusts. Hence, by Newton's second law,

$$f-f'=\rho a\Delta x\Delta y\Delta z. \tag{1}$$

Since we are interested in the thrusts on surfaces that contain a given point P, let the edge Δx of the cube shrink to zero length. If $\Delta x=0$, Eq. (1) becomes

$$f-f'=0. \tag{2}$$

Thus the thrusts parallel and antiparallel to the acceleration are equal. To understand how there may be acceleration under these circumstances, rewrite Eq. (1), introducing a negative sign because f decreases as x increases: $-\Delta f=\rho a\Delta x\Delta y\Delta z$, or $\Delta f/\Delta y\Delta z=\Delta p=-\rho a\Delta x$, where p represents pressure. Now, instead of letting $\Delta x=0$, let Δx approach zero as a limit, so that

$$\mathrm{d}p/\mathrm{d}x=-\rho a. \tag{3}$$

The acceleration thus depends on the pressure gradient. It is not a question of larger pressure in one direction than in another: pressure has no direction.

It should be noted that Eq. (3) is valid only when the pressure gradient and the acceleration are horizontal. It is not true in general that there will be acceleration whenever there is a finite pressure gradient. In a fluid at rest, for example, there is a downward pressure gradient, but no acceleration.

In the case of a viscous fluid in motion, the force on an immersed surface has in general both normal and tangential components, and does depend on the orientation of the surface. The pressure at a point may be completely described by giving the x-, y- and z-components of the forces, per unit area, on each of three small surfaces through the given point, perpendicular to the respective coordinate axes. (Only six of these nine data are independent.) The nine quantities, which are usually written in a square array of three rows and three columns, are the *components* of the pressure; that is, the pressure is a tensor of the second rank. In contrast to this, a vector quantity, which is completely specified by three components, is a tensor of the first rank.[1]

If the fluid is nonviscous, the situation reduces to the restricted case already discussed. Six of the components of the pressure tensor become zero, and the other three each equal what is usually called the ordinary, the hydrostatic, or

[1] As is well known, a scalar quantity, completely determined by a single term, is a tensor of zero rank. The rank of the tensor is the power to which the number of coordinates (in this case, three) must be raised to give the number of components.

the normal pressure. None of these adjectives is quite satisfactory. "Ordinary" is insufficiently descriptive; "hydrostatic" wrongly suggests a state of rest, or at least a necessary absence of acceleration; and "normal" implies direction. *Scalar* pressure would seem more appropriate.

Pressure is a property of the fluid at a given point. It is a useful mathematical quantity which enables us to calculate the force on an immersed surface, whatever its orientation. Of course the force has direction, but it is meaningless to say that any component of the pressure tensor acts in a given direction, or that the pressure itself acts in any direction or in all directions.

In a solid, as in a viscous fluid in motion, the pressure at a point is a tensor of the second rank, and, in certain cases, reduces to a scalar quantity. We may thus say with complete generality: ***pressure never has direction.***

The writer is indebted to Professor Harold C. Barker, of the University of Pennsylvania, for valued suggestions.

A New Point-Source Lamp for the Laboratory

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IT was the writer's privilege, for a short period during the war, to be engaged in developmental work for the Western Union Telegraph Company, Water Mill Laboratory. At this laboratory, under a contract issued by the Optics Section of the National Defense Research Committee, a new light source was developed. It is fundamentally a direct-current arc lamp constructed with permanent fixed electrodes which are sealed into a glass bulb filled with an inert gas. Because the arc activity is concentrated upon a small portion of the cathode, the lamp is called a Concentrated-arc lamp.

The cathode, the unique element of the new lamp, is made by packing zirconium oxide into the open end of a tube made of tungsten, molybdenum or tantalum, these metals being selected because of their high melting points. The anode, also made of a metal of high melting point, consists of a simple sheet or plate which has sufficient radiating surface so that during operation its color will be hardly more than a dull red.

The two electrodes are mounted in the glass bulb so that the exposed oxide surface of the cathode is but a few hundredths of an inch from and directly behind a hole in the center of the anode. The diameter of this hole is slightly larger than that of the cathode tube; this hole thus serves as a window for the emergence of light from the luminous spot on the cathode.

After the bulb has been evacuated and the electrodes outgassed, it is filled with an inert gas, usually argon, to a pressure slightly less than atmospheric. The cathode is then put through a "forming" process, in which a high, direct potential difference is applied across the electrodes, in series with suitable current-limiting resistors, so that an arc strikes between the anode and the metallic tube of the cathode. In a few seconds the cathode tube becomes red hot and raises the zirconium oxide packed in it to such a temperature that the oxide becomes an electric conductor. The arc then strikes between the anode and the oxide. Ionic bombardment raises the temperature of the surface of the oxide to or above its melting point at 3000°K. The molten oxide flows and bonds itself to the sides of the metal tube. After cooling, the end of the cathode presents a smooth glassy appearance, sometimes golden in color but often gray and metallic looking. It is thought that during the forming process some of the zirconium oxide is reduced to zirconium metal, which would account in part for the gray metallic appearance of the cathode. During operation the molten zirconium layer is so thin that surface tension holds it in place on the oxide, thus enabling the lamp to be operated in any position.

The Concentrated-arc lamp emits radiation from two principal sources: the white-hot zirconium cathode surface, and the cloud of excited argon gas and zirconium vapor that extends for a few thousandth of a centimeter from the cathode. The radiation originating in the cathode surface has a continuous spectral distribution and extends in measurable amounts from 2500A in the ultraviolet, through the visible, and on into the infra-red; the maximum energy

TABLE I. Operating data for standard sizes of Concentrated-arc lamps.

Nominal lamp rating (w)	Potential difference (v)	Current (amp)	Diameter of light source (mm)	Brightness (c/mm²) max.	Brightness (c/mm²) ave.	Luminous intensity (c)	Efficiency (c/w)	Life (hr)
2	37	0.055	0.085	96	56	0.32	0.155	175
10	21	0.5	0.40	55	22	2.7	0.26	700
25	20	1.25	0.73	40	21	8.7	0.35	800
100	15.4	6.25	1.50	52	39	77.0	0.80	1000

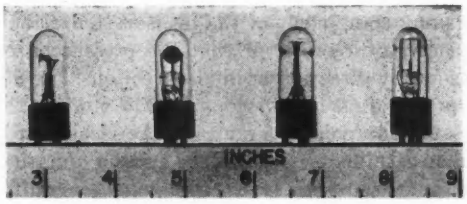

FIG. 1. Types of 2-w Concentrated-arc lamps.

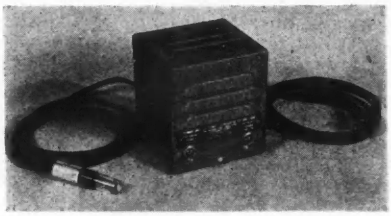

FIG. 2. Power supply for 2-w lamp.

is in the region of 10,000A. The radiation from the cloud of excited gas and vapor includes a continuum extending from the ultraviolet to about 5000A; the normal, singly and doubly ionized zirconium spectra; and the normal and singly ionized argon spectra.

Concentrated-arc lamps have been standardized at 2, 10, 25 and 100 w. In Table I important operating characteristics of these standard lamps are summarized. Two points of special interest in this table are: (i) the extremely small diameter of the light source, and (ii) the large value of the brightness. In normal operation ordinary tungsten-filament lamps have a brightness of about 10 c/mm². The Concentrated-arc lamp is therefore from two to five times as bright as a tungsten filament.

To start a lamp, a potential difference (1000 to 2000 v) must be applied to break down the gap in the lamp. When the lamp has become conducting, it may be operated from a rectifier, a direct-current generator, or a battery with the necessary ballast resistance in series to limit the current to its normal value. Power supplies operating from a 117-v, 60 c/sec a.c. line are available for all the standard lamps.

The various types of 2-w lamps are shown in Fig. 1, and the 2-w power supply which operates from a 117-v a.c. line is shown in Fig. 2. The lamps can be purchased from the manufacturer or through the various apparatus houses.

The primary purpose of this paper is to suggest certain ways in which the Concentrated-arc lamp, in particular the 2-w size, may be used in the student laboratory. The suggestions are not exhaustive, and most physics teachers will no doubt think of other uses for the lamp.

In Table I it will be observed that the diameter of the light source in the 2-w lamp is only 0.085 mm. Thus it is more nearly a point than is any other available source. Figure 3 is the shadow of a comb cast on a lantern slide plate. The distance from source to comb was 7 in., and that from source to plate was 14 in. Note the extreme sharpness of the shadow, an effect that can occur only when the source is extremely small. A further example of the formation of sharp shadows is noted in Figs. 4 and 5, which are shadows of a piece of 16-mesh copper wire screen. Here the distance from the 2-w source to the plate was 16 in. The wire screen was placed, in turn, 4 and 1 in. from the source, thus giving enlargements of 4 and 16 times. It will be observed that in Fig. 4 diffraction fringes are present. Such effects are of course unavoidable when objects of small dimensions are used and the proper distances chosen. More will be said concerning diffraction effects later.

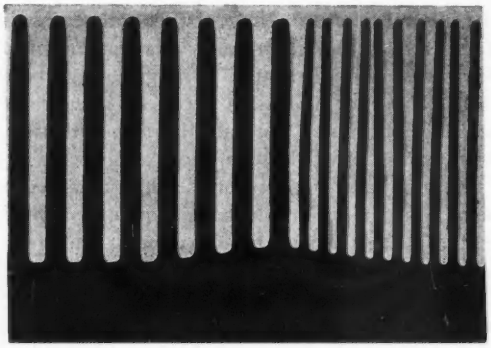

FIG. 3. Shadow of a comb. 2×.

The 2-w lamp lends itself well to a lecture demonstration of the linear propagation of light and the formation of shadows. An opaque ball 2 or 3 in. in diameter placed 2 ft from the lamp casts a very sharp shadow on a screen 16 ft away. Two lamps side by side afford a nice demonstration of umbra and penumbra.

A carbon-arc lamp is frequently used as a source in demonstrating the inverse-square law, but much better results may be obtained by using the 2-w lamp (a 25-w lamp of course gives a much higher intensity without much sacrifice in sharpness). This demonstration is carried out by placing a cardboard screen, in which is cut a 2-in. square, 1 ft in front of the luminous spot. A screen made of tracing cloth, upon which is

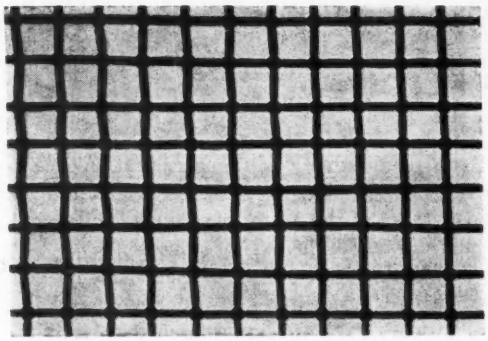

FIG. 4. Shadow of 16-mesh wire screen. 4×.

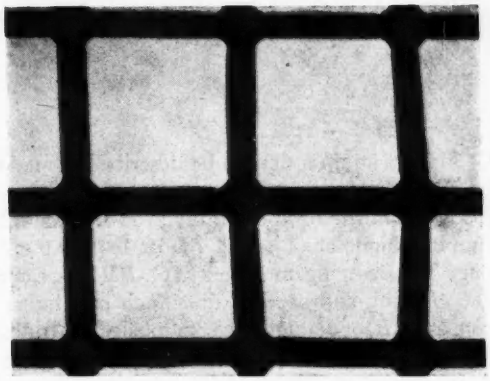

FIG. 5. Shadow of 16-mesh wire screen. 16×.

ruled an 8-in. square divided into 16 2-in. squares, is placed 2, then 3 and finally 4 ft from the spot. The light passing through the 2-in. square will cover 4, 9 and 16 squares, respectively. Such an arrangement illustrates the inverse-square law with remarkable exactness.

Another interesting and important use for the 2-w lamp is the demonstration of mirror and lens aberrations. For Jensen's excellent experiment on lens aberrations the 2-w lamp would be an improvement over the "point" source described in the article.[1]

For the demonstration of Fresnel diffraction, particularly for a circular opening or obstacle, the Concentrated-arc lamp has the advantage of being small, steady and very brilliant. We placed a penny, serving as the circular obstacle, at a distance of 4 m from the 2-w lamp and a screen 8 m beyond the penny. The alignment was accomplished by means of a telescope which was then replaced by a simple magnifier in order to observe the small bright spot in the center of the shadow. This bright spot is extremely small owing to the small size of the source. For photographic purposes one of the larger lamps would serve the purpose better (Fig. 6).

There are numerous other uses for the Concentrated-arc lamp, for instance, as a source for photographic enlarging and for photomicrography. In both instances considerable increase in the sharpness of the image is obtained. This is particularly advantageous in photomicrography, where considerable detail is desired. Some work has been done on this problem by the writer and further work is contemplated.

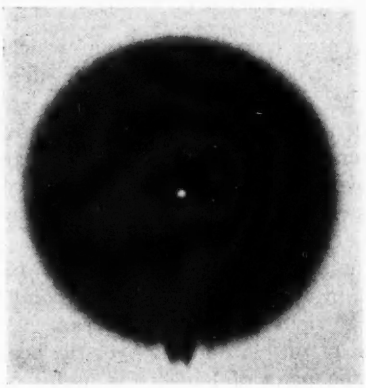

FIG. 6. Shadow of a penny. A 25-w Concentrated-arc lamp used as source. Distance from source to penny, 4 m; from penny to plate, 8 m.

The writer wishes to acknowledge his indebtedness to Mr. W. D. Buckingham, of the Water Mill, New York, Laboratory of the Western Union Telegraph Company for many valuable suggestions and criticisms and also for supplying Figs. 1 and 2.

[1] A. S. Jensen, *Am. J. Physics* **13**, 113 (1945).

Pendulums with Clamped or Loose Hangers

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THE pendulum first to be described is made from brass rod of rectangular cross section, $1\frac{1}{4}\times\frac{3}{8}$ in., in the form of an inverted U, broader than it is high. The beam AB (Fig. 1) is 60.0 cm long. The hanging members AC, BD are each 30.0 cm long and are in pairs. Each pair hangs from a pin E, of diameter 0.8 cm, placed centrally at the corner square. Tightening the wing nuts W, W, clamps the hangers in any desired position. At their lower ends the hanging members are kept $\frac{3}{8}$ in. apart by brass pieces F with suitable collars.

The central hole O in the beam, which serves for the introduction of the knife-edge K, is lined with a thin steel collar and is so bored that when the beam is resting on the knife-edge the latter is in the same straight line as the tops of the two pins E, E. The center of gravity of the beam itself is therefore 0.6 cm below the knife-edge.

In the experiment, the hangers are first clamped in a position so that they point downwards, at right angles to the beam. (A large template of tin plate fitting over the beam and within the pairs of hangers is useful for this setting.) The arrangement now constitutes a rigid pendulum, and the period is given by

$$T=2\pi\sqrt{(I/Mgh)}, \qquad (1)$$

where I is the moment of inertia of the pendulum about an axis through the point of support at right angles to the plane of swing, M is the mass of the pendulum, g is the acceleration due to gravity at the place of the experiment, and h is the distance of the center of gravity of the whole pendulum below the axis of support.

Calculation gives $T=1.87$ sec. This is confirmed by experiment.

The wing nuts are now loosened so that the hangers hang quite loosely. The pendulum is a pendulum no longer. It stays where it is put. One might say it is a pendulum with an infinite period of vibration except that even in an infinite time it would still be in the same position. The change in behavior from "hangers clamped" to "hangers free" is so striking that the workman who made the apparatus thought that something had gone wrong.

The experiment therefore illustrates the fact that pin joints will not transmit couples but only forces; and that when the hangers are hanging freely all their mass must be considered as concentrated at the point of support. The effective value of h with hangers free is, from the geometry of the arrangement, practically zero.

The arrangement of hangers "hanging loosely" is very akin to that of the ordinary chemical balance. With the balance however, care is taken to get the common center of gravity below the central knife-edge so that the balance will be stable and will vibrate about its central position when disturbed.

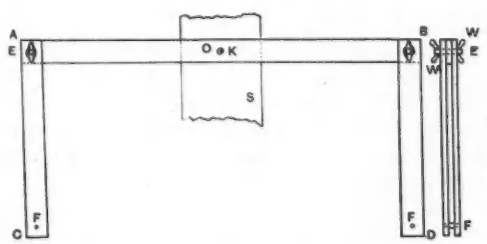

FIG. 1. A pendulum with appendages that may be clamped or hung from pin joints.

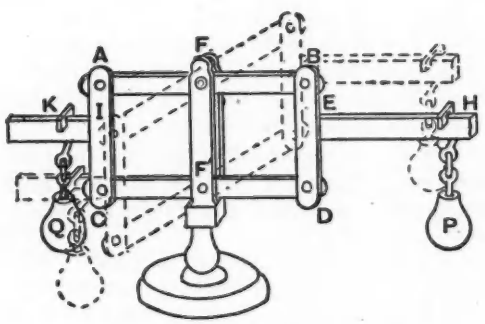

FIG. 2. Roberval balance, invented in 1670. [*Dictionary of Applied Physics.*]

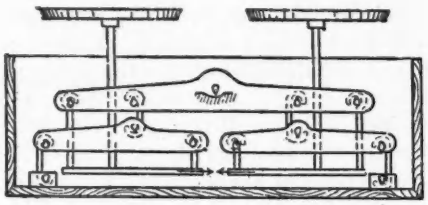

FIG. 3. Beranger balance. The loads on the pans are transmitted to subsidiary beams arranged below the main beam, which, in turn, transmit forces, always vertical and equal to the loads, to the knife-edges of the main beam. [*Dictionary of Applied Physics.*]

Our arrangement calls to mind the Roberval paradox or balance. This balance is shown in Fig. 2.[1] Briefly A, B, C, D, F, F' are all pin joints, the arms EH and K of equal mass are rigidly attached to the verticals BD, AC, respectively, and equal masses P and Q balance wherever they are hung from the horizontal arms.

A student who tries to use the principle of moments to explain its working is nonplused until he realizes the properties of the pin joints. If he uses the principle of conservation of energy, the explanation (as indicated by the dashed diagram in Fig. 2) is obvious from the first. Hence the paradox.

The explanation of the action of the common Beranger balance (Fig. 3) is, on the face of it, more complicated; but, as explained in the *Dictionary of Applied Physics*, can easily be seen to follow the same general principles.

I suggest it would be well if students should spend some time studying the actions of the common instruments they use. Balances and watches are taken for granted, whereas there are more mechanical principles illustrated in these common laboratory devices than in many of the class experiments.

Further variations of the pendulum of Fig. 1.—The adjustable hangers may be clamped in other positions, thus giving rigid pendulums of different shapes. Thus in Fig. 4*a*, with the arms turned inwards at an angle of 45°, the period is 1.65 sec; in Fig. 4*b*, with the arms turned outward at 45°, the period is 2.68 sec; with one arm up and the other down, as in Fig. 4*c*, the period is about 9 sec. In this last case, h, computed from Eq. (1), has a value of 0.4 cm, which agrees closely with the geometry of the frame. Experiment and calculation tally in all cases. The beam alone has a period of about 4.6 sec, giving $h=0.6$ cm, which agrees with its dimensions.

[1] Taken from the *Dictionary of Applied Physics*, vol. 3, article, "Weighing machines," 3.1, p. 810, to which reference may be made for its construction and mode of operation.

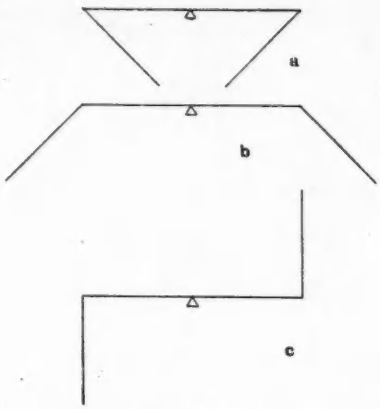

FIG. 4. Modifications of the pendulum of Fig. 1.

Professor Wm. Schriever, of the University of Oklahoma, has suggested as another variation a pendulum of different shape (Fig. 5) which the present author developed and had made from brass rod of rectangular cross section, $\frac{3}{4}\times\frac{1}{8}$ in. The vertical arm AB (Fig. 5) is a single rod of length 52.0 cm. The two horizontal arms CD, EF are double and 108.0 cm long. They are double for symmetry and are kept $\frac{1}{8}$ in. apart by collars near their ends. There are two pins at A and B so that the rods may be kept loose or tightened

TABLE I. Periods of pendulum of Fig. 5.

Conditions	Period (sec)
Vertical rod alone	1.4
Both arms clamped	3.5
Top arm free, lower arm clamped	3.1
Top arm clamped, lower arm free	2.9
Both arms free	2.2
Both arms clamped and loaded	4.3
Both arms free and loaded	2.3
Both arms clamped, lower arm loaded	2.6
Both arms clamped, upper arm loaded	unstable
Both arms free, lower arm loaded	1.7
Upper arm free, lower arm clamped, both loaded	3.5
Upper arm clamped, lower arm free, both loaded	3.4
Upper arm removed, lower arm clamped	1.5
Upper arm removed, lower arm free	1.0
Upper arm removed, lower arm clamped and loaded	1.9
Upper arm removed, lower arm free and loaded	1.1

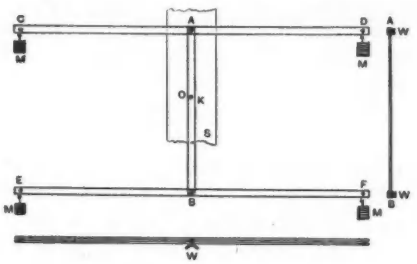

FIG. 5. Another type of pendulum.

together with wing nuts as before. A hole is bored through the vertical arm AB at a point O so that when the knife-edge K is in position, the distance from K to the pin at A is 20.0 cm, and the distance from K to the pin at B is 30.0 cm.

The pendulum can be swung with the horizontal arms present or absent, clamped or unclamped, and the differences in the periods noted. When the nuts are unclamped there is much damping, and sometimes only two or three vibrations can be observed.

This pendulum has an advantage that sets of slotted weights of equal mass M may be hung by little S-hooks from the connecting pieces at C, D, E, F, and the periods further changed. In all cases calculation and observation of periods agree fairly well. The results in Table I show how the period changes with conditions. The mass M of each hanging weight is 500 gm, and this is equivalent to the mass of 57 cm of rod. In calculating periods it is easiest to take the mass of unit length of a single rod as the unit of mass.

Demonstration Experiments: Mechanical Analogs of Electric Circuits

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IN elementary discussions of electric oscillatory systems, it is usual to mention a loaded spring as a mechanical analog. Some students are helped by the analogy to see the inertia and force characteristics of the electric system. It is hardly worth exhibiting as an actual demonstration because of its lack of close resemblance to the electric system. There is nothing to represent the wires connecting the condenser to the inductance; in fact, there is no sign of a complete circuit. (Some students even make the mistake of confusing the coiled spring with the coil of the inductance!)

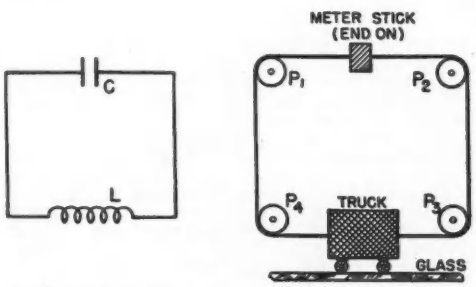

FIG. 1. Oscillatory system and mechanical analog.

The models described here not only provide more lifelike analogs but work so well that they are worth the trouble of setting them up as demonstrations. The first model represents a simple oscillatory system. The second is an analog of an a.c. circuit with L and C branches in parallel; it shows the transmission of alternating currents of different frequencies, below, at and above resonance. In both models there are complete circuits of string, and they resemble the electric systems closely.

When acoustic systems are shown as circuits, with equivalent mechanical and electric circuits, beginners find them puzzling because the acoustic circuits appear incomplete—actually they are completed by concealed "grounds." Here again mechanical models with complete circuits are helpful.

Oscillatory system.—A taut loop of string running round four pulleys P_1, P_2, P_3, P_4 forms a vertical rectangular "string circuit" corresponding to the wires in the circuit joining inductance L and capacitor C (Fig. 1). A massive truck running to-and-fro on a table is attached midway between P_3 and P_4 to correspond to the

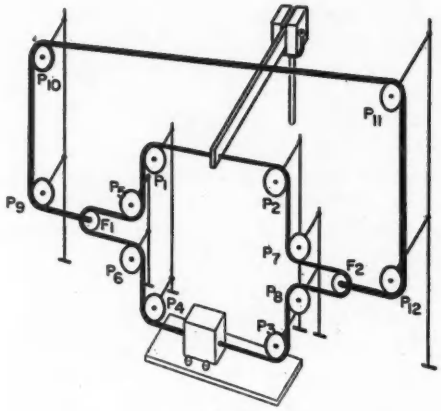

FIG. 2.

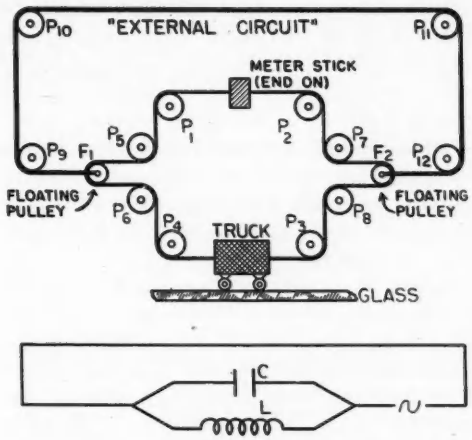

FIG. 3.

FIGS. 2 AND 3. "Filter system" and mechanical analog.

inductance. A flexible lath (meter stick) bending to-and-fro corresponds to the capacitor C. The lath is level with the upper portion of string and perpendicular to it, having one end clamped and the other end attached to the string midway between P_1 and P_2.

When the truck is displaced and released, the system oscillates with damped simple harmonic motion. Quadrupling the inertia of the truck by adding load doubles the period. The string moves with an alternating "current." The motion of the strained meter stick may be imagined to represent displacement current.

The four pulleys should be attached to firm supports and should have good ball bearings. The truck should have ball-bearing wheels running on a smooth level surface, say glass. A mass of two or three kilograms is suitable. It is convenient to make the meter stick horizontal, though it could be vertical with the clamped end high above the circuit.

"Filter system" showing parallel resonance.—This model, an elaboration of the preceding one, has two separate strings (Figs. 2 and 3). Extra pulleys, P_5, P_6, P_7, P_8, extend the oscillatory string circuit of Fig. 1 and enable it to be connected in an "external circuit" of string that runs round four pulleys, P_9, P_{10}, P_{11}, P_{12}, and is attached at each end to the *axle* of a floating pulley. These floating pulleys F_1 and F_2 are light ball-bearing, single-sheave pulleys. They are not attached to fixed supports. The string of the oscillatory loop circuit runs round the wheels of these floating pulleys; and it is kept taut, and they are kept floating, by the pull of the external circuit string. The other twelve pulleys, $P_1 \cdots P_{12}$, should have good ball bearings and should be attached to fixed supports on the table.

An alternating force applied by hand to the string of the external circuit—or, better still, to the axle of one of the floating pulleys—causes an alternating "current" of string motion. The arrangement simulates the electric circuit shown in Fig. 3 (except that the current in the external string circuit gives twice the algebraic sum of the currents in the two branches of the loop instead of just the sum).

If a high frequency is used, the meter stick moves to-and-fro a lot and the truck remains almost stationary. If a low frequency is used, the truck moves to-and-fro (slowly!) and the meter stick hardly bends at all. At an intermediate, resonance frequency, both meter stick and truck move with large amplitude in opposite phases. At resonance frequency the hand in the external circuit moves very little, but feels considerable force.

All the pulleys must be good ones with little friction, and the strings must be taut. It may be better to replace the meter stick by two sticks clamped side by side.

Safeguards on Laboratory Apparatus

C. J. Overbeck
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THE laboratory instructor is concerned with apparatus safeguards both as protection of the equipment and protection for the student. The degree of safeguarding essential to a well-conducted laboratory is not fixed. The persons responsible for continued smooth operation of the laboratory may wish for extreme foolproofness. It must be remembered, however, that the student can learn a great deal by making errors. Some instrument loss is teaching money well spent.

To avoid extremes one should try to answer two questions before applying an artificial safeguard: (*i*) will it impair the teaching effectiveness of this apparatus and (*ii*) will the probable loss of equipment resulting from lack of the safeguard deprive other students of their chance to carry out the experiment?

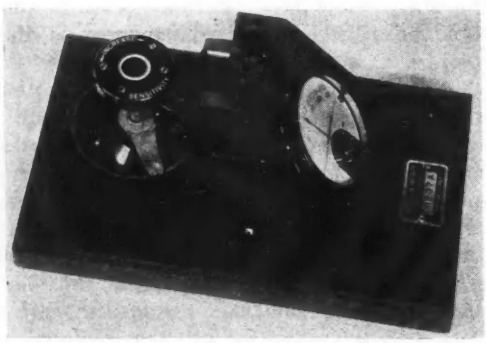

Fig. 1. Galvanometer with shunt.

The following simple, workable safeguards are not necessarily new, but some of them may have escaped attention.

Galvanometer protection.—Figure 1 shows how our galvanometer mortality was changed from a bad risk to a safe bet. The beginning student has little idea of the probable currents in a circuit. Nor is he aware of the need for protecting a galvanometer by using a shunt circuit. By making the plainly marked shunt an integral part of the unit, the new students do protect the galvanometer, perhaps partly because of the resulting convenience of operation. Later in the course his past experience produces proper procedure when he is given the unprotected instrument.

Dropless-weight hangers.—Why do scientific apparatus companies not capitalize to a greater extent on the sale of "dropless-weight hangers"? Every laboratory instructor has regretted frequently the interruptions, confusion and possible discomfort to the student resulting when precariously piled weights topple over at inopportune times. Several simple designs would serve to prevent such occurrences. The type shown in Fig. 2 is in use in our laboratory. The hanger shown is a rod of steel bent into a **U** with its legs fixed into a flat crossbar. The weights, shaped as shown, cannot jiggle off. Incidentally, these hangers pile compactly when stored. Note also that the apparatus of Fig. 2, for determining the Joule equivalent, has been built to include simple belt guards as protection to the students.

Lens guards.—It is not an uncommon practice

Fig. 2. Weight hangers.

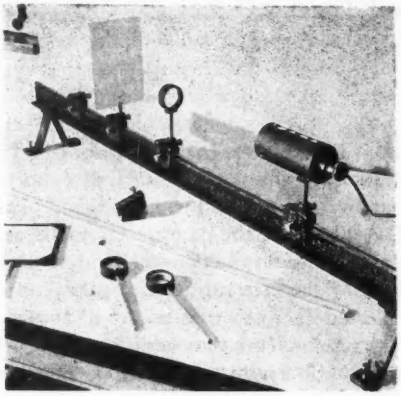

FIG. 3. Lens guards.

to protect lenses by fitting them into a frame of slightly greater width than the lens thickness (Fig. 3). Thus the lens is not scratched when placed on the table top and is also partly protected if dropped. A better grade of lens can, therefore, be used since the higher initial cost is offset by longer life.

Open snapswitch.—Another simple device which should be incorporated into more apparatus is the normally open snapswitch, a switch that is closed only while held in that position by the student. The student, having many new things to think about, is liable to forget a closed circuit. Some equipment, such as knife-type heaters, are easily ruined as a result. When such unprotected equipment is used, the instructor necessarily must spend time trying to protect it, thus neglecting important constructive teaching tasks. In Fig. 4 is shown a snapswitch installed on a gas laws apparatus. Since its installation

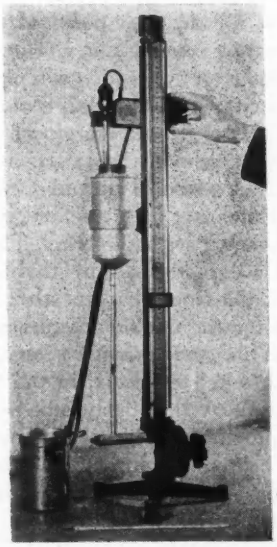

FIG. 4. Snap switch on gas laws apparatus.

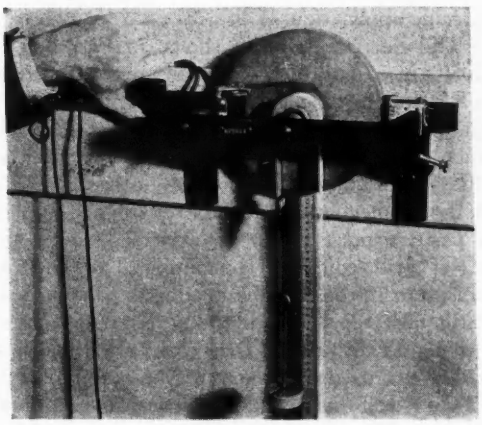

FIG. 5. Modified time recorder.

several years ago, no new knife-type heaters have been purchased.

Time recording.—Certain experiments require a time record. High potential spark timing is commonly employed, but there are several drawbacks to its use in the elementary laboratory. Another method is to use a magnetically operated scribe that slides along a paraffined paper strip and moves laterally to produce a time mark when an electric time-impulse arrives. The friction between the scribe and tape is high and, what is worse, variable. To eliminate this, set the scribe or time marker to strike down when the time impulses are impressed, as shown in Fig. 5. It then makes only momentary contacts with the paper, producing dots similar in appearance to spark marks. This permits high accuracy. Such a magnetically controlled unit is seldom out of order.

Photoelectric Interval Timer

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Oberlin College, Oberlin, Ohio

THE timer described is designed for use in the many laboratory experiments which demand an accuracy greater than that obtained by stop watch methods. The timing circuit is controlled by double occultation of a light beam, giving measurements free from mechanical interference and allowing considerable flexibility for specific application.

The electric circuit is shown in Fig. 1. Two 2050's in a "scale of two" circuit are controlled by a PJ22 photo-tube. At the start of a measurement the left-hand 2050 is conducting and the photo-tube is illuminated. An abrupt decrease in illumination raises the potential of the upper end of the 0.5-megohm photo-tube resistor and applies a positive pulse to the thyratrons through the 0.1-μf grid coupling capacitors. The positive pulse causes the right-hand tube to conduct and extinguish the left-hand tube. The contacts of the plate load relay *R* then close, thus applying 110 v a.c. to the primary of the counter step-down transformer and operating the impulse counter *C*. Re-establishment of the light beam on the photo-tube produces a negative grid pulse, which has no effect on the thyratrons. The second positive pulse, occurring when the light beam is again cut, restores the initial condition and stops the counter. In case the right-hand tube is conducting, the correct starting condition is secured by cutting off the light beam with the hand. A switch in the counter circuit is used to prevent changes in the counter reading owing to accidental light interruptions. A pilot lamp may be inserted across the counter transformer secondary to indicate the condition of the circuit.

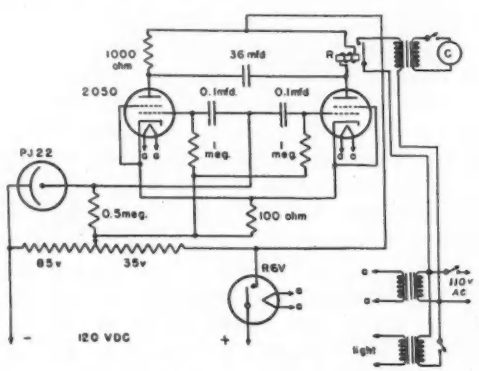

FIG. 1. The electric circuit.

Since the Cenco impulse counter records 2 div for each cycle, on 60-c/sec a.c. 1 div corresponds to 1/120 sec. The accuracy of the timer depends upon the accuracy of the a.c. power available. If greater precision is desired, the output of a standard frequency generator may be used to drive the counter.

The grid coupling capacitance depends upon the velocity with which the light beam is cut and must be large enough to pass pulses that will fire the thyratrons. For the circuit constants shown in Fig. 1 the timer has a lower velocity limit of about 2 cm/sec. Since a high resistance must be used with the photo-tube, the large time constant of the grid circuit requires a large plate coupling capacitance, for the time constant of the plate circuit must be several times that of the grid circuit. Satisfactory operation was obtained with a plate capacitance of 20 μf, but for low velocities 36 μf provides a greater margin of safety. The telephone-type relay *R* has a d.c. resistance of 500 ohms. It closes on 20 ma and opens on 12 ma. The 1000-ohm plate load resistor gives a rough impedance match with the relay. The choice of 120 v d.c. was made because this voltage was readily available from a bank of storage batteries. Batteries have the double advantage that they simplify the timer and provide a constant voltage supply. No switch is needed in the 120-v plate supply as the R6V time delay tube performs this duty and prevents application of plate voltage before the heaters are turned on. The circuit is stable and noncritical even though only low voltage direct current is used.

The optical system is shown in Fig. 2. The source is mounted on the right-hand side of the bottom rack and consists of an automobile

* Now at Douglas Aircraft Company, Inc., Santa Monica, California.

spotlight bulb with appropriate condenser lenses. The filament is brought to a focus about halfway across the bottom rack, and then the beam is made nearly parallel and reflected upward along the left-hand side. At the upper rack the beam again becomes horizontal and is brought to focus on a plumb line above the lower focal spot. The optical path ends in a spot that covers the width of the photo-tube. The width of the light beam is about 3 mm at both focal points, although with large weight pans a wider portion of the beam will be cut. It is therefore desirable to keep the optical system symmetrical so that the positions at cut-off will be accurately known. The top rack is adjustable, allowing the distance between the beams to be varied. All optical elements are fitted with sliding mounts on plywood tracks for easy adjustment. The light source is run on 6.3 v a.c. and is controlled by a separate switch.

The timer was built for use with a rotating cylinder viscosity apparatus. Velocities of the weight driving the cylinder may be measured over distances up to 150 cm with this arrangement. Small variations in viscosity are easily detected. Most results obtained by careful students vary by less than 0.05 sec. These variations are real and are not caused by inaccurate timing. The apparatus may be calibrated by measuring the time of descent of a freely falling body. A close approximation to zero initial velocity is obtained by releasing a rod of small diameter when its lower end is tangent to the light beam. Results accurate to within 1 percent have been obtained with a rod 1.3 cm in diameter falling through a distance of 152 cm.

This suggests that the timer could be used in an improved free-fall experiment for first year students. Most students are confused by the equal time intervals recorded on waxed tape by a freely falling body. A direct confirmation that $s=\frac{1}{2}gt^2$ can be obtained. The student can measure the slope of the line obtained by plotting distance as a function of time squared and thus get the value of g. Measurements with various initial velocities are easily accomplished for demonstration that $s=v_0t+\frac{1}{2}gt^2$. Direct measurements of both distance and time should go far toward removing the difficulties caused by tape measurements and yet keep the experiments reasonably accurate.

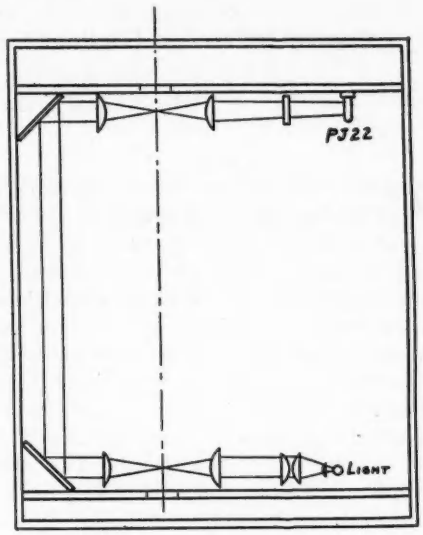

FIG. 2. The optical system.

A timer of this type should be of use in many laboratory problems. For instance, it might be applied to control a high speed circuit of the type described by Uffelmann[1] for applications where the accuracy demanded exceeds the counting rate of the mechanical impulse recorder. The circuit is simple and has been found reliable during two semesters of student use. Various changes in circuit constants and arrangement of the optical system should present no serious difficulties.

[1] F. L. Uffelmann, *J. Sci. Instruments* **15**, 222 (1938).

Curiosity is one of the most permanent and certain characteristics of a vigorous intellect.—SAMUEL JOHNSON.

Coarse Diffraction Gratings for Lecture Demonstration and Laboratory

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DEMONSTRATION of the diffraction of light by coarse gratings made by the photographic reduction of ruled lines can be done effectively and economically by almost anyone. It is possible to rule with black ink, a few hundred uniform closely-spaced lines on drawing paper and to make one or more photographic reductions of this drawing. This has been done before, probably by many, but those who tried it have experienced the difficulty of ruling many lines of equal spacing and equal width. The almost inevitable irregularities of hand ruling limit the useful reduction that can be made, and they may blur the diffraction images at all reductions.

To circumvent the tedium and the inaccuracies of hand drawing, commercially prepared parallel lines on engravers' masks have been used to make a slide with several reductions to show the diffraction of light by gratings of several degrees of coarseness. Details of construction and use of this slide will be given as a guide to those who may care to prepare a demonstration of this kind. Other procedures for the making of gratings have been reported by Schultz[1] and Wertenbaker.[2]

Demonstration of the diffraction of light is often made by passing light from a slit source through a commercial replica grating. The diffracted light is then brought to a focus on a distant screen by means of an optical system. Demonstrations of this kind with relatively good gratings showing well-defined spectra are not rendered less important or desirable by the present suggestion, which is primarily designed to supplement the usual grating demonstrations. The main purpose of the experiment here described is to emphasize the simplicity with which coarse gratings can be made, and to show the progressive improvement in the formation of spectra as more and more lines per unit length are used.

On a standard $3\frac{1}{4}\times 4$-in. lantern slide five rectangular apertures, $\frac{3}{4}\times\frac{3}{8}$ in., were cut one above another in regular black masking paper, with $\frac{1}{8}$ in. of black paper between successive apertures along their long dimensions. The top aperture was left blank to show the direct beam; the second aperture was covered with a piece of film having 15 lines/cm; the third aperture, with film having 30 lines/cm; the fourth aperture, with film having 60 lines/cm; and the fifth aperture, with film having 120 lines/cm. The slide may first be used in the usual lantern slide projector to show the parallel lines, which can readily be seen in two or three of the apertures. It may then be placed in a suitable optical system to show at once how light from a slit source is diffracted by the four gratings on the slide.

Of the several projection systems tried, the one that gave the best results in a lecture room of seating capacity 200 will be described. An arc lamp having impregnated carbons and condenser lenses was operated with 25-amp direct current to illuminate a vertical slit approximately $\frac{1}{2}\times\frac{1}{32}$ in. The slit was placed in a position where the lantern condenser brings the light from the arc to a rough focus. A spherical lens was so placed that a sharp image of the slit, suitably enlarged, was formed on a distant screen. The composite grating was then set close to this lens on the side nearer to the screen, and each grating produced its own set of spectra on the screen. However, instead of being arranged in order, one above the other like the gratings that produced them, they were all superimposed approximately in a single band at the level of the original slit image. The reason for this is that the face of the grating is completely out of focus on the screen. Each spectral line is an image of the slit diffracted horizontally, without regard to what part of the lens and grating the light forming it came through.

In order to separate the spectra formed by the several gratings, a cylindrical lens with axis horizontal was inserted between the grating and screen placed at such a distance as to produce the best image. Then the two lenses form an astigmatic optical system such that slit and

[1] W. W. Schultz, *Am. J. Physics* **12**, 105 (1944).
[2] C. Wertenbaker, *Am. J. Physics* **13**, 51 (1945).

screen are conjugate foci for vertical lines, while grating and screen are conjugate for horizontal lines. Definition can generally be improved by narrowing the slit as much as is consistent with the need for sufficient illumination, and by adjusting the spherical lens both in position and orientation. Most of the projection lenses found in lecture equipment, even though they are achromatic, have very small angular fields and hence give poor images unless the optic axis is correctly alined.

Specification of the system actually used is presented for the benefit of those who may wish to reproduce this demonstration. The spherical lens was of diameter 3 in. and of focal length 48 cm; the cylindrical lens was of the same diameter and of focal length 50 cm. Distances were as follows: 52 cm from slit to spherical lens; 63 cm from spherical to cylindrical lens; 526 cm from spherical lens to screen.

Several orders were visible in each spectrum, though the third order from the finest grating was very weak, and many orders overlapped seriously in the spectra from the two coarse gratings. A bright orange line, due to sodium, showed clearly in most spectra, and it was used for making measurements. For the 120-lines/cm grating, the first-order orange line was displaced 3.75 cm from the central beam, the second order at twice this value; for 60 lines/cm, the first order was at 1.80 cm; and for 30 lines/cm, it was 0.93 cm. Use of the ratios of these distances to 526 cm for the sines of the angle of diffraction leads to values of the wave-length of 5940, 5700 and 5890A, respectively.

Gratings of this kind can be used also in the laboratory. With a mercury arc and spectrometer, the wave-length of the 5461A line was found to be 5330A when measured in the second and third orders produced by the grating having 120 lines/cm. However, it may be that the photographic reductions were not made with as high precision as believed, and this experiment might well be used as a calibration of the grating space. In other words, the discrepancy between the measured and known wave-lengths may arise from an inaccurately known grating space.

The engravers' mask used to make this composite grating is known as Zip-A-Tone Screen No. 52 and is manufactured by the Paratone Company. The 8×12-in. screen costs about 50 cts. Larger size screens and screens of different rulings or designs are also available. In the present work, use was made of the same photographic emulsions as are ordinarily employed in making lantern slides. It is entirely possible that with films of unusually fine grain, considerably greater reductions could be made.

IT is unfortunate that the laws upon which electrical measurements are based do not readily link up to form a similar logical development of the theory of the subject; but once we recognise the great difference between the basic experimental laws and the theory which has been devised as the simplest workable system consistent with these laws, we are prepared to find differences of opinion as to which theoretical scheme can be used with the least risk of confusion. An outstanding fact, and one that reassures the experimentalist, is that all the doubt and discussion surrounding "theoretical," or idealized, experiments seems to produce no repercussions on his own real experiments.
—L. HARTSHORN, *Nature* **154**, 534–537 (1944).

Mechanical Aids for the Solution of Linear Equations

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A SYSTEM of n linear equations with n unknown $x_1x_2\cdots x_n$,

$$\begin{aligned} A_1x_1+B_1x_2\cdots+N_1x_n&=P_1,\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot&\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot&\\ A_nx_1+B_nx_2\cdots+N_nx_n&=P_n, \end{aligned}$$

has the determinantal solutions

$$x_i=\begin{vmatrix} A_1B_1\cdots H_1P_1\cdots N_1\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ A_iB_i\cdots H_iP_i\cdots N_i\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ A_nB_n\cdots H_nP_n\cdots N_n \end{vmatrix} : \begin{vmatrix} A_1B_1\cdots I_1\cdots N_1\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ \cdot\quad\cdot\quad\cdot\quad\cdot\quad\cdot\\ A_nB_n\cdots I_n\cdots N_n \end{vmatrix},$$

where $i=1, 2, \cdots, n$. When the unknowns exceed three, the development of the determinants demands patience and close attention, although as such it is merely mechanical work. It was therefore thought possible that processes might be devised which would practically eliminate the occasions for mistakes.

The law for the development of determinants, namely, that each product may contain only one element of the same row and column, points the way to a method for mechanizing the process.

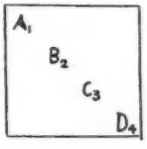

FIG. 1. Diagonal product of a fourth-order determinant.

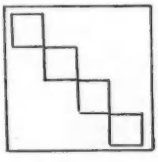

FIG. 2. Stencil with slots for diagonal product.

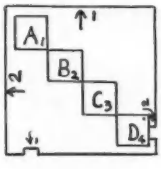

FIG. 3. Stencil superimposed on diagonal product.

If we take a determinant of fourth order,

$$\begin{vmatrix} A_1B_1C_1D_1\\ A_2B_2C_2D_2\\ A_3B_3C_3D_3\\ A_4B_4C_4D_4 \end{vmatrix},$$

$A_1B_2C_3D_4$ is one of the products of the sum. When all the other elements of the determinant are disregarded, this product takes the form shown in Fig. 1. If we make a stencil as shown in Fig. 2, where the small squares represent slots, and cover the determinant with this stencil, we obtain the result shown in Fig. 3.

As the product is positive or negative, depending on the number of inversions, this stencil would have to be marked +, but we shall see later on that another method exists for determining the sign. At first thought it would appear that 24 stencils are required for a determinant of the fourth order, but a glance at the stencil shows that by turning it 90° it also furnishes the product $A_4B_3C_2D_1$, likewise positive. We now recall that the value of a determinant of the third order may be obtained by repeating the two first columns and by forming the six diagonal products from top and bottom. So we repeat for the determinant of the fourth order the first three columns as shown in Fig. 4. It is evident that by shifting the stencil parallel with itself we can successively read off the products

$$A_1B_2C_3D_4,\ B_1C_2D_3A_4,\ C_1D_2A_3B_4,\ D_1A_2B_3C_4,$$

which are alternately positive and negative.

A_1	B_1	C_1	D_1	A_1	B_1	C_1
A_2	B_2	C_2	D_2	A_2	B_2	C_2
A_3	B_3	C_3	D_3	A_3	B_3	C_3
A_4	B_4	C_4	D_4	A_4	B_4	C_4
+	−	+	−	+	−	+

FIG. 4. Fourth-order determinant with first three columns added.

Therefore, in Fig. 4 the columns are alternately marked plus and minus, and the proper sign appears in the small slots of the stencils at the left-hand bottom corner.

Turning the stencil 90° and repeating the process, we obtain four additional products, again alternately positive and negative and starting with $+A_4B_3C_2D_1$. For the remaining 16 terms we use the stencil shown in Fig. 5. This stencil is used four times, taking first the side lettered H with the arrowhead marked *3* pointing upwards and starting with the product $+A_1B_3C_4D_2$. Shifting the stencil toward the right furnishes $-B_1C_3D_4A_2$, $+C_1D_3A_4B_2$, $-D_1A_3B_4C_2$. We then turn the stencil 90° so that the arrowhead marked *4* points upward and repeat the process, thus obtaining $+A_4B_1C_3D_2$, $-B_4C_1D_3A_2$, $+C_4D_1A_3B_2$, $-D_4A_1B_3C_2$. Then the reverse side of this stencil, marked T (Fig. 6), is used with the arrowheads marked *5* and *6* successively upwards and always observing the sign in the small slot at the left-hand bottom corner. To avoid any mistakes these slots are marked with the same numbers as the arrowheads to which they apply.

We have so obtained the expanded expression for the denominator determinant of four equations with four unknowns. Now we proceed to describe the mechanical device for forming the numerator determinant needed to solve the equations

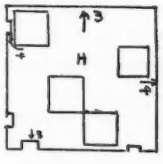

FIG. 5. Stencil used for forming eight products.

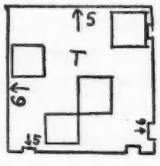

FIG. 6. Reverse side of stencil shown in Fig. 5.

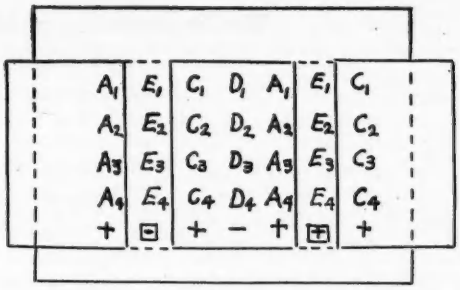

FIG. 7. Guide for forming numerator determinants.

$$A_1x_1+B_1x_2+C_1x_3+D_1x_4=E_1,$$
$$A_2x_1+B_2x_2+C_2x_3+D_2x_4=E_2,$$
$$A_3x_1+B_3x_2+C_3x_3+D_3x_4=E_3,$$
$$A_4x_1+B_3x_2+C_3x_3+D_4x_4=E_4,$$

for x_1, x_2, x_3, x_4. On a sheet of paper of sufficient strength we mark off two columns of the length and width of those shown in Fig. 4 and separated the width of four columns from each other. Both columns contain the letters E_1, E_2, E_3, E_4. Then four cuts are made along the heavy lines of these columns, and two small squares are cut out at the bottom of each, as shown in Fig. 7. Now Fig. 4 is cut along the heavy outside lines and is used as a slide by pushing it under the two E-columns, as shown in Fig. 7. It is easily seen that by setting the slide so that one of its columns is replaced by an E-column we are forming the numerator determinant for the unknown of which the coefficients have been replaced.

The development of these determinants is carried out in the same manner as before, by aid of the stencils. In this way the solutions for the unknown as mentioned in the beginning have been obtained. There are other mechanical arrangements possible, as for instance, writing the denominator determinant on a cylindrical surface and wrapping the stencils around this cylinder so they can be turned. A second method would be to write the determinant on a circular disk where sectors take the place of columns and rings the place of rows. In this case, the stencils would also be disks with the slots distributed so that each sector and ring contains only one.

The Presentation of Mass to the Undergraduate

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THE purpose of this paper is to urge that the concept of mass be more clearly presented by those who write for undergraduates. In order that this be accomplished, it would be very helpful if physicists would agree on what they want the term *mass* to represent. The next step—that of expressing this clearly conceived idea in such terms that the student could comprehend it—would then be relatively simple.

At present, the writers of college physics textbooks, many of whom are physicists of note, differ as to the definition of mass, some defining mass as quantity of matter, others as inertia, and many discussing it in vague terms. Some few authors write of gravitational mass. This is indeed permissible, but it complicates the use of the term mass unnecessarily. In regard to the attraction of one particle of matter for another particle of matter, it is correct and leads to a simpler treatment to say that there is a gravitational force of attraction between two bodies of inertial masses m_1 and m_2. This is actually what is done experimentally, for m_1 and m_2 are determined in practice by weighing the bodies on a platform balance, which is really determining the inertias of these bodies. Then the experimenter may proceed to determine the gravitational force of attraction between the two bodies. Hence one way of presenting this phenomenon in elementary physics is to consider the gravitational force of attraction between two bodies of known inertial masses, and thus not bring in the new concept of gravitational mass. If this view is taken, then the problem of what the term mass should represent resolves itself into whether mass should be defined as quantity of matter or as inertia, or perhaps as being a function of quantity of matter or of inertia.

To make the following remarks more lucid, let us state explicitly the definitions of quantity of matter and of inertia that are believed to be most commonly accepted. Quantity of matter, as the term indicates, is the number, or quantity, of units of matter in the body. Theoretically, this would result in the definition that the quantity of matter in an uncharged body is the number of neutrons, protons and electrons in the body, according to the theory most widely accepted at present. Experimentally, a definition for quantity of matter is provided by the standard kilogram, but this is satisfactory only so long as material of the same isotopic content as the standard kilogram is dealt with. In terms of this definition, quantity of matter of other substances would have no meaning.

"Inertia is that property of matter because of which a force must be exerted on a body in order to accelerate it" is the statement by one author of what is believed to be the accepted definition or understanding of inertia. Quantitatively, the inertia of a body is found by using either the second or the third law of Newton. If the second law is used, inertia is equal to F/a; or, at the same place and at the same time, the inertias of two bodies can be compared by letting the attraction of the earth produce the same acceleration on the two bodies, whereupon one says that the ratio of the inertias of the two bodies is equal to the ratio of the pulls of the earth on the two bodies. This is the principle utilized in weighing a body with a platform balance. If the third law is used, the ratio of the inertias of two interacting bodies is equal to the negative inverse ratio of the changes in their velocities; $\Delta V_1/\Delta V_2 = -m_2/m_1$.

Most authors define unit mass, the gram, as the one-thousandth part of the standard kilogram. Rarely does one find the unit mass defined as the inertia of a definite amount of matter. Hence most authors implicitly define the unit mass as a quantity of matter. To be consistent, they should express the unit of mass in the same terms that they use in defining mass. The following quotations indicate how far apart authors are in giving a clearly conceived idea of mass. These quotations have been selected from among our best and most widely used college text- and reference books, from all parts

of the country, and arranged in chronological order from 1892 to the present time. Of course, connected with these quoted statements there are usually paragraphs amplifying the definitions, which paragraphs are often helpful in clarifying the author's concept. However, the quotation selected was, in each case, the author's most direct statement as to what mass is—the statement that gave his concept of mass, so far as could be ascertained from reading the book. The names of the authors have been omitted, so that attention will be put, not on what any one person thought or said about mass, but on the differences held and the vagueness exhibited by physicists in general in regard to the concept.

(1) By motion Newton means what in modern scientific language is called momentum, in which quantity of matter moved is taken into account as well as the rate at which it travels. . . . Equal masses . . . consist of equal quantities of matter, or, in modern language they are equal in mass. . . . Any two bodies are of equal mass if equal forces applied to these bodies produce, in equal times, equal changes of velocity. This is the only definition of equal masses which can be admitted in dynamics, and it is applicable to all material bodies, whatever they may be made of.

(2) If two portions of matter have the same inertia, or if they have the same weight with reference to the earth at a certain point, they may be defined as having the same quantities of matter. The quantity of matter in a body is ordinarily called its "mass"; and so equal masses may be defined in either of these two ways.

(3) The mass of a body is the measure of its inertia.

(4) The measure of the inertia of a body is called its mass. . . . The process of weighing, being simple and accurate, takes the place of the more difficult process of comparing masses by comparing their inertias.

(5) The mass of a body is in one sense the body itself, that is, the matter of which it is composed. . . . It thus appears that the real indicator of the magnitude mass is not volume, nor even weight, but inertia. . . . Two bodies of precisely the same inertia and mass may have different weights, if they are in different places. Perhaps this is not a thoroughly satisfying definition of mass; but until more is known with certainty as to what inertia is and how one body can have more of it than another body of the same size and shape, it will be very difficult to arrive at a really good definition of the term.

(6) It is therefore mass or inertia, and not weight, which is the more fundamental property of bodies, for weight is the chance value of the force of the earth's pull on the mass. . . . Mass is the inertia of a body or its resistance to motion. . . . The unit of mass is the inertia of 1 cm^3 of water at 4°C.

(7) Quantitatively we think of the mass of a body as a quantity determining the amount of matter in a body.

(8) The measure of the force which has acted on a body to alter the state of its motion is the product of the latter's inertia (often called Mass) by the acceleration produced.

(9) A new term, mass, is therefore used for the quantity of matter in a body, in order to distinguish it clearly from the weight of the body. . . . In general, when equal forces act on different masses, the less the mass, the greater the acceleration. This principle leads to a broader conception of mass than is given by the definition . . . ; thus, mass is that property of a body by virtue of which a force must be exerted on it in order to give it acceleration; this property is also spoken of as inertia.

(10) In order to compare these inertias quantitatively, Newton introduced the concept of mass. . . . Masses, or amounts of inertia, of bodies are proportional to their weights.

(11) Mass. A basic physical magnitude pertaining primarily to matter (though having an interpretation also, in modern physics, with reference to electricity and to energy); the measure of which is found in its relation to inertia.

(12) Inertia is a measure of the mass . . . the amount of matter in a body. Mass is not to be confused with weight. Weight is the force with which the earth attracts a mass.

(13) The inertia of a body is the sum of the inertias of its several parts; . . . It is for this reason that the quantity of matter in a body, or its mass as it is called, is measured by its inertia as compared with that of some standard piece of matter taken as the unit of mass.

(14) Anything having mass has inertia. In fact, the two terms really mean the same thing, and are inherent in what we know as matter, regardless of where it may be found. . . . Mass is a measure of a body's inertia, and would not be altered if the force of gravitation were to change or even vanish.

(15) The mass of a body is usually defined as the quantity of matter in the body, but we have no way of ascertaining what this means by direct sense perception . . . masses can be compared or measured only by using forces.

(16) Matter has inertia. . . . It is this property of inertia which, better than all else, measures the amount of matter—its mass.

(17) Mass, or matter, is recognized as something occupying space. The mass of a body is the quantity of matter in it and is constant regardless of position.

(18) Mass is defined as a quantitative measure of inertia. Inertia and mass are both measured in grams or pounds.

(19) By the mass of a body we mean the quantity of matter it contains. This will clearly be the same anywhere in the universe.

(20) Mass is the inertia or sluggishness which an object, when frictionlessly mounted, exhibits in response to any effort made to start it or to stop it or to change in any other way its state of motion.

(21) A man who lifts a bag of sugar from the grocer's table may, at the moment, be concerned with its weight; but when he dines, he is concerned with the amount of food he acquired, with the number of crystals or molecules he brought home, with that unchanging property of the sugar that is called its mass. . . . The inertia of a body is made the measure of its mass, after the fashion of an experiment described in the next article. A body is said to have mass, to have inertia, and to have weight. Some attempt at a differentiation might be made by saying that matter is mass, exhibits inertia, and experiences weight. Mass is sometimes inadequately defined as the amount of matter in a body, but this statement must be supplemented by adding that this "amount of matter" is arrived at through observing the body's acceleration by a force.

(22) Mass is therefore a measure of a body's inertia. Newton considered mass to represent the "quantity of matter" in a body. . . . The mass of a body refers to the amount of matter in it and is everywhere the same.

(23) Another very important unit is that of mass, by which is meant the amount of matter in a body.

(24) The mass of a body cannot be more definitely described than to say that it is that quality to which are due both its inertia and its gravitational action. The mass is sometimes described as the quantity of matter in the body. This description is useful so long as we compare quantities of the same sort of matter, but fails to have a definite meaning for other cases.

(25) Mass is a measure of "quantity of matter" as exhibited by the property of inertia.

(26) The physicist chooses to measure quantity of matter by that property which he calls mass, ... The constancy of this property, mass, is a strong argument for its use in measuring matter. . . . But the inertia of a body is proportional to what we shall call the mass of the body.

Thus it seems probable that originally mass referred to quantity of matter, defined in terms of the material in the standard kilogram. Then, if the same force acted on two different portions of these materials, the inertias of these portions were inversely proportional to the accelerations produced, as were the quantities of matter on which the force acted. Furthermore, if suitable units were chosen, the numerical value of the inertia as determined by such an experiment would be exactly the same as that of the quantity of matter. It then followed that when the inertia was determined the quantity of matter, that is, the mass, was determined, all three having the same value. Mass was identical with quantity of matter, and inertia was a property of matter, which property was experimentally measured. The quantity of matter, the mass, of any substance was said to be determined by its inertia.

However, as experimental knowledge increased, difficulties in this line of reasoning were encountered. The inertia of a helium atom is not four times as great as that of the ordinary hydrogen atom, even though theory indicates that the quantity of matter in the helium atom is four times that in the hydrogen atom. The inertia of an electron having a velocity approaching that of light is not the same as that of an electron moving slowly with respect to the observer. The electron still represents, so far as is known, the same quantity of matter in the two cases; but the inertias in the two cases are measurably different.

Again, when fission is produced in a uranium atom, the number of each of the fundamental particles stays the same, that is, the quantity of matter is the same, but the total inertia of the matter after fission is less than that of the same matter before fission. From such experiments as these, it now seems that the inertia of matter can change, and the quantity of that matter, so far as is now known, remains the same. Inertia is what is measured.

From the definitions of mass previously quoted it is seen that some physicists now want to identify mass with inertia. There is an increasing trend in this direction. The term quantity of matter is sometimes dropped, since, in general, there are no known units in terms of which to measure it. It is recognized, however, that there is such a thing as matter, and force acts on matter —on a large amount or on a small amount. It thus seems entirely permissible for an author to identify mass with inertia.

If he does, it is hoped that he will be consistent and not write, for example, of a mass of 10 g being acted on by a force, but of a body of 10 g being acted on by a force; nor will he write of the kinetic energy of mass m nor of the mass being at rest, nor of the energy being absorbed by the mass. In each case it is hoped that he will substitute the word *body* or *matter* for the word *mass* as here used. Matter and quantity of

matter would still be important concepts, but would not be mass. Mass, that is, inertia, would be a property of matter.

Some physicists, however, would like to distinguish between inertia and mass, defining inertia as a property of matter, and mass as the quantitative measure of inertia. But if this permissible distinction were decided upon, one should no longer say that the inertia of a body is the sum of the inertias of its parts, or that two bodies which have equal inertias are said to have equal masses, or that the inertia of two equal bodies is twice the inertia of each body; for in these statements inertia is used in a quantitative sense.

It seems wisest to accept that definition of a term for which there is the greatest usage, provided there is no valid scientific objection. There would probably be the least change in the present vocabulary of physics, if mass were identified with inertia. One may well ask, then, why have the two terms, mass and inertia, if their meanings are identical. One answer is that both exist, and this identity has come about by the development of physical concepts through recent advances. However, it is noticeable that the term inertia is not being used very frequently at the present time.

If in the judgment of an author it is best to define mass as quantity of matter, then it is hoped that he will be consistent in the use of this definition and not write that the electron has gained mass nor that in the fission of a uranium atom mass is transformed into energy; but will say that the electron has gained inertia and that in a fission, inertia is transformed into energy. Quantity of matter, that is, mass, then has the property, inertia. It should be noted, furthermore, that if mass is identified with quantity of matter, as defined in this paper, then mass is not proportional to the inertia of the body, even when it is at rest, because of the inertia defect observed when the fundamental particles combine to form atoms. It is inadvisable, therefore, to identify mass with quantity of matter, as it would involve so many changes in the present vocabulary of physics.

Thus it would be well to consider dropping the term gravitational mass and the definition of mass as quantity of matter; furthermore, to decide whether mass is to be identified with inertia, or with quantity of inertia. For the sake of the student who is trying to grasp the concepts of physics, may there be greater clarity in the presentation of the concept of mass in the textbooks!

In Physics, Too?

CERTAINLY, at a time when much is heard about the organization of historical research and its endowment, it deserves consideration whether the greatest historical work has not in this country always been lit from an inward individual fire, and moved by an impulse which was in essence not didactic nor educational nor political, but intensely subjective; the need on the part of the inquirer to explore for his private satisfaction the secrets of the past, and perhaps afterwards to display according to his own desire the trophies of his fond adventuring.—The London Times, Aug. 17, 1946.

An Old Mathematical Instrument—The Sector

DOUGLAS RENNIE HUDSON
University of Leeds, England

LAST autumn I bought for a few shillings in an Edinburgh junk shop the engraved ivory rule illustrated in Figs. 1 and 2. When asked the purpose of the instrument and use of the various scales, the shopman confessed his ignorance, but, in view of its preservation, did not regard it as an antique. The "sector" was a standard component of sets of drawing instruments a century and a half ago. In the *Penny Cyclopedia*, published by Charles Knight and Company, 22 Ludgate Street, London, in 1841, the description occupies over a column and a half. The gradual decline in the use of this once popular instrument is clear from the space devoted to it in books of reference. The ninth edition of the *Encyclopedia Britannica*, published in 1886 in Edinburgh, has no entry for "Sector," while *Rees's Cyclopedia*, published about 1820 by Longman's, has no less than eleven and a half columns.

On inquiry, the Science Museum, South Kensington, was unable to trace "D. Davis, London" whose name appears on the rule, but stated that a firm of the name of Davis Brothers, 33 New Bond Street, existed in 1820 and suggested that the name "D. Davis" may refer only to the vendor. The Keeper, Mr. A. Barclay, furnished me with a most useful set of references.

Through the good offices of Dr. Richard Offor, Brotherton Librarian to the University, a copy was procured through the Central Loan Scheme, from University College, London, of

THE DESCRIPTION and vſe of the SECTOR.

The Croſse-ſtaffe and other Inſtruments.
For ſuch as are ſtudious of Mathematicall practiſe.

AT LONDON
Printed by Williã Jones.
and are to be sold by:
Edmund Weauer.
1624.

It is dedicated to John, Count of Bridgewater, Viscount of Brackley and Baron of Ellesmere,

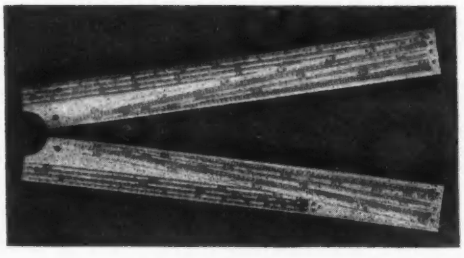
HONORATISSIMO DOMINO *Dn* IOHANNI COMITI de *Bridgewater*, VICECOMITI de BRACKLEY, BARONI de ELLESMERE

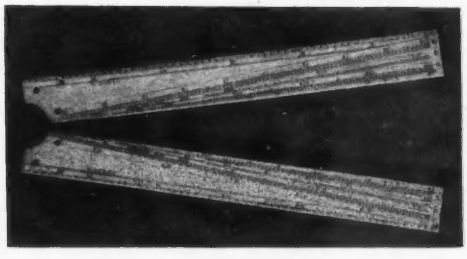
and has an inscription

Hæc organa *M*
Sectorem
Radium
Arcum
Quadrantem D. D. D.

The title-page (Fig. 3) shows very clearly how these instruments are used. At the beginning is an engraving from both sides (Fig. 4) which shows a remarkable resemblance to the author's sector. Unfortunately, the announcement at the top of Fig. 4 has been mutilated by binder's cropping:

These instruments are wrought in brasse by [Elias Adam dwelling] . . . over against St. Clements Church: and in wood by Iohn Thompson dwelling in Hosiar lane and by Nathaniell Gos Dwelling at Ratclif





FIGS. 1 AND 2. Obverse and reverse of the author's ivory sector.

The volume carries signatures of James Grix 1761, Hevingham, and Jn° Warner 1787. On the engraved title-page (Fig. 3) is an ink scribble something like "48, 8-6-1627" or "Pr. 4-6-1627," perhaps a bookseller's or library number, or the price and date. However, it seems unlikely that the present rule is as old as the book, in view of (*i*) the use of ivory rather than brass or wood and (*ii*) the absence of signs for the planets on it (compare Figs. 1 and 2 with 4). As purchased, the ivory was darkened but not greatly discolored. At the suggestion of the author's colleague, Dr. L. A. Moignard, it was freshened by rubbing with dilute acetic acid, following Mrs. Beeton's recommendation of vinegar for yellowed piano keys; how successfully can be judged from Figs. 1 and 2.

The sector seems to have been a sort of general purpose instrument, applicable in arithmetic, mensuration, trigonometry and spherical geometry. But this was essentially a practical man's equipment: on page 135 is a calculation to obtain the mass of similar bodies, for example, spheres, in different metals. Stuck on the blank space at the bottom of the page is a table for seven metals with their corresponding planetary signs (Fig. 5); it gives the densities of these relative to gold, to four significant figures. This was not originally part of the book.

On page 60 is an astronomical diagram divided into hours. At the center a plot of the constellations cut from another page has been ingeniously fixed, so as to rotate about a common center (Fig. 6). At the end of the part dealing with the sector is "The Conclusion to the Reader."

> It is well known to many of you, that this sector was thus construied, the most part of this book written in latin, many copies transcribed and despersed more than sixteene yeares since. I am at the last contented to give way that it come forth in English. Not that I think it worthy, either of my labour or of the publique view, but partly to satisfy their importunity; who not understanding the Latin, yet were at the charge to buy the instrument, and partly for my owne ease. For as it is painefull for others to transcribe my copie, so it is troublesome for me to give satisfaction herein to all that desire it. If I find this to give you content, it shall encourage me to do the like for my Crosse-Staffe, and some other Instruments. In the meantime beare with Printers faults, and so I rest.
>
> E. G.
>
> Gresham Coll. 1 Maij 1623
>
> FINIS

FIG. 3. Engraved title-page from Gunter's textbook, published in 1624.

In the "First Book of the Crosse-Staffe" there are numerous scribbles and manuscript corrections, particularly in that portion dealing with numerical calculations.

In the same binding with these two is the "*Canon Triangulorum* or Tables of ARTIFICIAL Sines and Tangents to a *Radius* of 10000,0000 parts and each minute of the Quadrant. By Edm. Gunter, Professor of Astronomie in Gresham College. 1623" This concludes with:

> The vse of the Canon.
>
> This Canon hath like vse as Tables of right *Sines* and Tangents set forth by others, but the practise somewhat more ease. For keeping the rules, and working by these Tables, you may vse addition instead of their multiplication and subtraction instead of their division, and so resolve all spherical triangles without the help of *Secants* or *versed sines*.
>
> If any desire the like for right-angled triangles, he may adjoyne the *Logarithmes* of my old Colleague & worthy friend M. Henrie Briggs. For both proceed from the same ground, and so require the same manner of work; as I often shew in my publique lectures at Gresham College: where I rest
>
> Friend to all that are studious of Mathematical practise
>
> E. G.

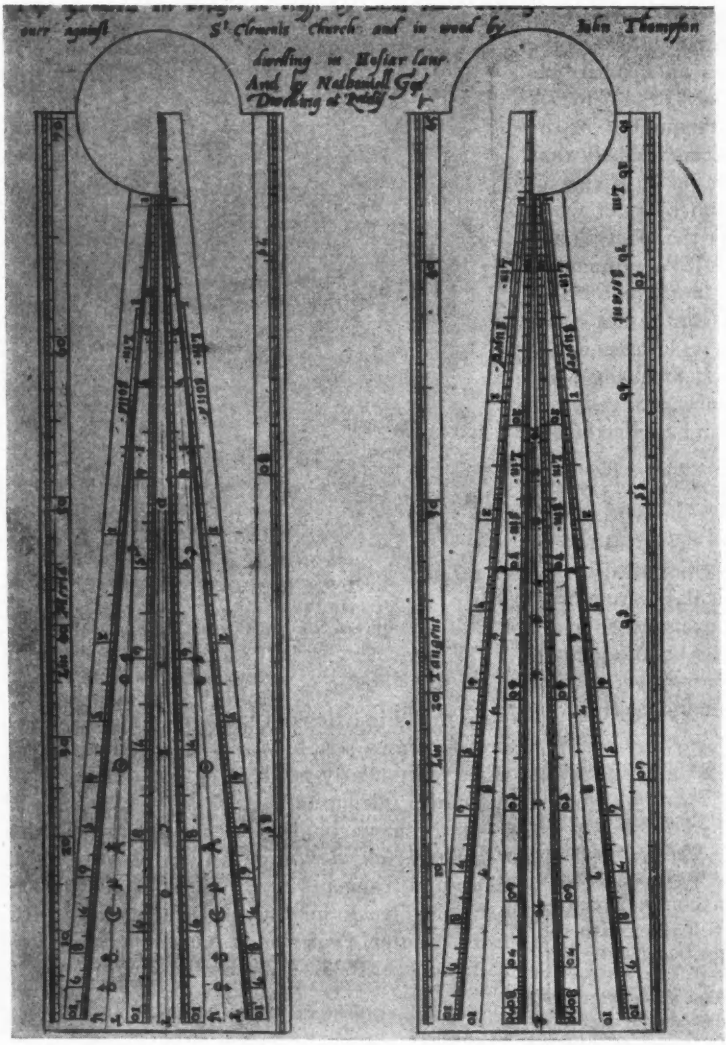
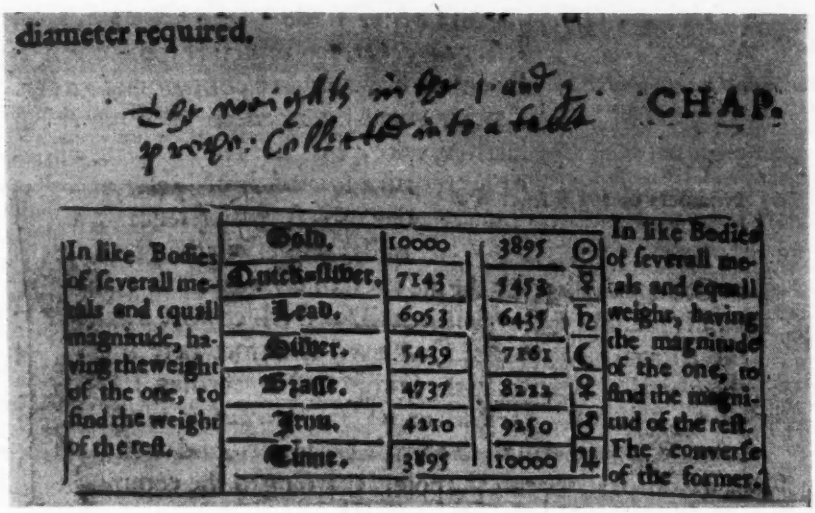


FIG. 4. Illustration of a sector in Gunter's textbook, showing zodiacal symbols; compare with Figs. 1 and 2.

Gresham College was in 1660 or earlier the meeting place, probably the first in London, of the Royal Society. It was founded by Sir Thomas Gresham (1519–79), alumnus of Caius College, Cambridge University, and endowed munificently under his will. In 1597 seven professors were appointed, to read a lecture daily, on astronomy, geometry, physic, law, divinity, rhetoric and music; Gresham professors have included many famous names. Gresham himself became wealthy as a result of trading with the Low Countries; but, apart from being a shrewd merchant, he was a noted economist, best known for Gresham's law—"bad money drives out good." He frequently acted as consultant to Edward VI and Henry VIII, and was financial agent and Ambassador to Parma, under Queen Elizabeth. In 1565 he founded the Royal Exchange.

Use of the scales.—By 1841 the sector must still have been well known as a drawing and surveying instrument, as is obvious from the


diameter required.

by weights in the 1 and 2 water. Collect to into a table. CHAP.

In like Bodies of severall metals and equall magnitude, having the weight of the one, to find the weight of the rest.	Gold.	10000	3895	☉
	Quicksilver.	7143	5453	☿
	Lead.	6053	6435	♄
	Silver.	5439	7161	☾
	Brasse.	4737	8222	♀
	Iron.	4210	9250	♂
	Tinne.	3895	10000	♃

In like Bodies of severall metals and equall weight, having the magnitude of the one, to find the magnitud of the rest. The converse of the former.

FIG. 5. Ink scribble on page 135 at the end of a calculation of the masses of similar shapes in different metals. Stuck on the bottom is a table of densities of seven metals relative to gold, and their planetary symbols.

FIG. 6. Gnomonic dial divided into hours from 4 A.M. to 8 P.M. A diagram of constellations cut out from another page has been ingeniously fixed in, to rotate on a common center.

following description condensed from the *Penny Cyclopedia*.

An instrument invented by GUNTER, which has the appearance of a small carpenter's rule marked with scales in every part; the greater number of these scales not being laid down parallel to the edges of the rule, but converging towards the pivot. The sector is a large number of pairs of compasses packed up into one, and most explanations of the instrument attempt to describe them all in one.

1. A line of *polygons* marked POL, showing the sides of polygons inscribed in a circle. The radius of the scale is the distance from the pivot.

2. A line of *chords* as above described, the radius being the chord of 60°. But it is to be noted that upon the common sector the whole length of the scale is only the chord of 60°, so that angles above 60° do not appear.

3. A line of *sines*, the radius of which is the sine of 90°.

4. A line of *secants*, usually extending to about 75°, the radius of course being the secant of 0°. This scale is blank up to 0°.

5. A first line of *tangents*, from 0° to 45°, the radius being the tangent of 45°, or the whole length of the rule.

6. A second line of *tangents*, on a smaller scale, beginning at 45°, and proceeding to about 75°, the radius being the tangent of 45°.

7. A line of equal parts to find a fourth proportional to three numbers.

The sector becomes an incorrect instrument, comparatively, when a great opening is required, and also when the result is much greater than the data from which it is produced. So much accuracy of construction is necessary, that those to whom the instrument is often really useful (not many, we suspect) should rather procure the larger ones, which are manufactured by the best instrument makers, than be content with the six-inch lines which are found in the common cases of instruments. The sector is an instrument which requires more care than the common scales, and in the use of which expertness can be gained by nothing but practice. Each scale is a pair of parallel lines with cross divisions; and it is important to note that the compasses must be applied to the inner of the parallel lines in every case. Also when the compasses are in the hand, with one point laid on one of the scales, the other scale being about to be moved to bring the other point of the compass on the right division of the counterpart scale, take care to hold the compasses only by that leg which is laid down on the scale.

It is desired to thank very heartily Mr. J. Manby, F. R. P. S., Photographer to the University, who took the photographs at very short notice for the author's convenience.

Cultural Predicament

PRESCIENTIFIC men can neither build nor maintain a scientific culture. Man, the toolmaker, has still to fashion the tools for his own reworking, lest he use the tools he has already made for the witless purpose of his own undoing. So long as men use science to solve only their material problems, by their very successes they create problems of higher order and of more grave significance: the mightier the battleship, the more desperate the need to remove the motives for its use. In no other fact is our predicament as a world culture more starkly dramatized than in the frenzy with which we employ science to manufacture weapons with which to preserve—not to eliminate but actually to preserve—the prescientific customs and institutions to which science is so inevitably opposed. We wage war fervently in order to defend, so we proclaim, the very culture that is warlike in its deeply cherished traditions. We staunchly preserve and persistently nourish our nationalistic and other group loyalties in ways that serve to disunite the peoples of the earth. And we use the *techniques* of science to achieve these ends which are inimical to the time-binding implications and practical possibilities of the general *method* of science. We are working at cross-purposes with impressive vigor. Not only does the left hand not know what the right is doing; it is undoing it.—WENDELL JOHNSON, *People in quandaries* (Harper, 1946), p. 384.

Reproductions of Prints, Drawings and Paintings of Interest in the History of Physics

27. "Travelling on the Liverpool and Manchester Railway"

E. C. WATSON
California Institute of Technology, Pasadena 4, California

THE Liverpool and Manchester Railway, opened in 1830, demonstrated that a revolution had taken place in the methods of transportation of both goods and people. Its success was also a great stimulus to mechanical invention since it was for it that the first high speed locomotive of the modern type was invented and constructed. The interesting story of this pioneer railway has often been told[1] and need not be repeated here. Instead, its early days will be recalled to memory by the reproduction of the famous pair of aquatints, entitled "Travelling on the Liverpool and Manchester Railway," published in 1831 by RUDOLPH ACKERMANN.

The interest aroused by this first great railway line led to the publication of a considerable number of prints and other illustrations. The most beautiful series was that drawn by T. T. BURY, engraved by H. PYALL, and published during 1831 by ACKERMANN.[2] It consisted of 13 hand-colored aquatints, 10 by 8 in. in size, dealing with typical views along the railroad, such as "Entrance of the Railway at Edge Hill, Liverpool," "Excavation of Olive Mount, four miles from Liverpool," "Viaduct across the Sankey Valley," "View of the Railway across Chat Moss," "Entrance into Manchester across Water Street," "Near Liverpool, looking towards Manchester," "Rainhill Bridge," "Taking in Water at Parkside."

Late in 1831 two oblong plates, drawn by I. SHAW and aquatinted by S. G. HUGHES, were published by ACKERMANN, each measuring 26 by 8 in. Both are entitled "Travelling on the Liverpool and Manchester Railway" and depict two trains, one above the other (Plates 1 and 2). The "Train of the first class of carriages, with the mail" is hauled by the "Jupiter," a locomotive of the "Planet" class, incorrectly shown with four equal wheels, and has a comparatively modern-looking four-wheeled tender. The "Train of the second class, for outside passengers" is drawn by the "North Star," an improved "Rocket" with the primitive water barrel tender. The engine of the "Train of waggons with goods, etc., etc.," named "Liverpool," is of the "Bury" type with coupled wheels. This engine ran on the line for some little time in the early days, but never became the property of the company. The

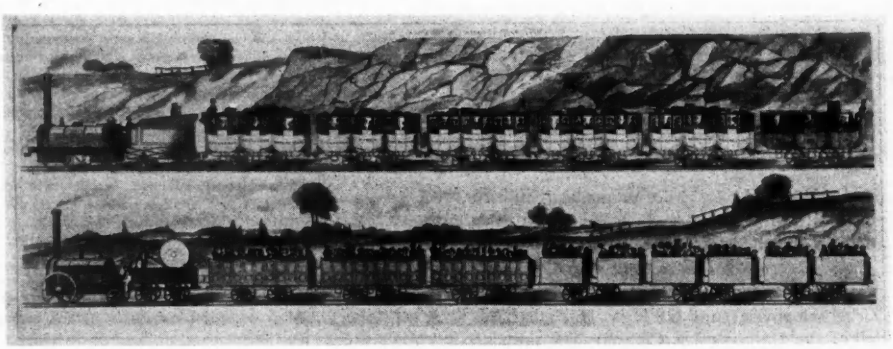


PLATE 1. Trains for passengers.

[1] Hardly a book has been written about railways that does not refer to the L & M. An annotated bibliography of the most important references will be found in C. F. Dendy Marshall's article, "The Liverpool and Manchester Railway," *Trans. Newcomen Soc.* **2**, 35 (1921).

[2] *Coloured views on the Liverpool and Manchester Railway* (London, 1831).

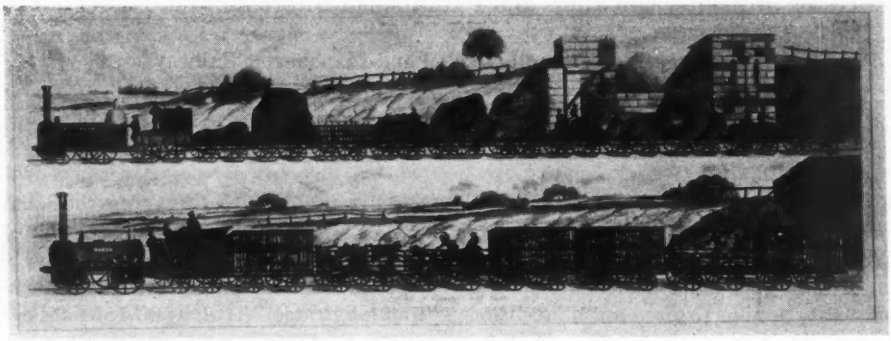


PLATE 2. Trains for goods and cattle.

locomotive of the "Train of carriages with cattle" is an excellent representation of the "Fury," which had a splasher on the driving wheels and a respectable tender with a cast-iron frame.

The original plates from which these prints were struck, were later reworked and at least three states of the impressions exist, each with minor variants.

Committee on Physics for Students of Biology and Medicine

A MEETING of the Association's committee to promote more effective teaching of physics for students of biology and medicine was held on June 17–19, 1946, at Evanston and Chicago.

During the preliminary discussion by the committee, examples of physical principles drawn from the fields of biology and medicine were presented as typical of the kind of illustrative material that should stimulate a greater interest in physics among students of biology and medicine. The committee felt that a proper choice of such material would also strengthen the course for the liberal arts students.

The committee was in agreement that a collection of such illustrative material along with problems and experiments, in the form of a reference book for the teacher and student of physics, would be a valuable contribution. This book is provisionally to be referred to as a "source book."

The general problem of physics for premedical students was later discussed with Professor C. I. Reed and other members of the department of physiology at the Medical College of the University of Illinois, and with Dr. Victor Johnson (physiology), Dr. Kenneth S. Cole (biophysics), Dr. R. E. Zirkel (biophysics) and Dr. F. W. H. Zachariasen (physics), all of the University of Chicago. The proposal of a "source book" was presented and illustrative examples prepared by Dr. Strait and some of his colleagues were offered for criticism. It was agreed by the group that the preparation of a "source book" should be an effective procedure and plans were discussed for obtaining the active cooperation of biologists and medical educators in supplying illustrative examples. Dr. Reed suggested the names of several potential authors of such material.

Dr. Cole discussed with the committee a proposed second course in physics for students of biology and medicine. The chairman presented a preliminary outline of such a course, asking for criticisms and additions.

The final discussion of the committee may be summarized as follows:

(1) The committee will attempt the joint editorship of a "source book" of examples of physical principles found in biology and medicine for the use of teachers and students of physics. Dr. Strait agreed to be the chief editor.

(2) All members of the committee will assist in preparing material for the book and in enlisting the services of contributing authors.

(3) Due credit is to be given to all contributors to the book.

(4) When a variety of material has been prepared, the members of the committee will cooperate in sampling teacher opinion on the usability of such material.

(5) Additional financial support for the work of the committee will be necessary.

(6) The American Association of Physics Teachers will be asked to sponsor the "source book" as it did *Demonstration Experiments in Physics*.

(7) It is anticipated that financial support for publication must be sought.

(8) The committee will continue work on the second course for students of biology and medicine; eventually, a mimeographed syllabus of the course will be prepared for circulation among biologists and medical educators for criticism.

The committee gratefully acknowledges the financial support for its preliminary work provided by the Baruch Committee on Physical Medicine.

LESTER I. BOCKSTAHLER
LOUIS A. STRAIT
LEROY L. BARNES, *Chairman*

NOTES AND DISCUSSION

A Graphical Comparison of the Fahrenheit and Centigrade Temperature Scales

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IT is desired to know at times at what temperature the Fahrenheit reading F is N times the centigrade reading C. From the relations, $F=NC$ and $F=(9C/5)+32$, there

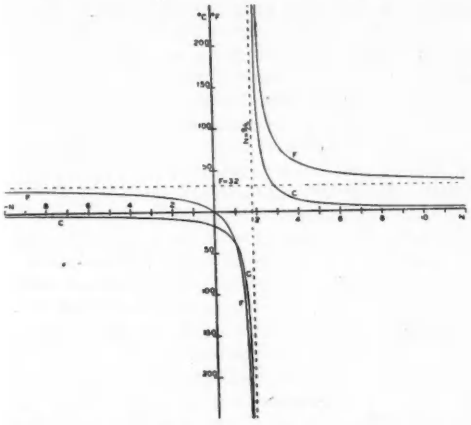

FIG. 1. Fahrenheit and centigrade readings as functions of N; $F=NC$.

result the following two hyperbolic equations connecting C with N and F with N, respectively:

$$NC-(9C/5)-32=0, \quad (1)$$
$$NF-32N-(9F/5)=0. \quad (2)$$

By plotting these relations on a common graph (Fig. 1) it is easy to obtain at a glance the desired information. Fractional and negative values of N are, of course, also included.

A Simple Inexpensive Accurately-Timed Spark

ARTHUR G. ROUSE
St. Louis University, St. Louis 3, Missouri

THE construction of a free-fall apparatus similar to Cenco No. 74950 calls for an accurately-timed spark that periodically passes through a metal plummet which falls between a vertical wire and a vertical flat surface supporting a wax-coated paper on which is recorded the position of the plummet at the instants the spark occurs. The first apparatus, built in our shop, incorporated a 100-c sec^{-1} tuning fork to interrupt the current in the primary of a Ford spark coil. Values of g obtained covered a wide range. Erratic sparking at the spark coil breaker points probably was the cause.

It was thought an electronically controlled spark should prove more reliable. Since a thyratron (gas-triode) tube has the characteristic of suddenly passing a plate current when the grid potential passes through a critical value, the abrupt change in current presents the possibility of inducing a voltage by passing this current through the primary of a spark coil. Furthermore, if a.c. voltages are employed for the tube potentials, the process can be repeated during each cycle of the supply voltage.

The actual circuit employed is shown schematically in Fig. 1. In it R_1 and C_1 provide the necessary phasing so that the grid attains the critical potential at the desired point in each cycle; R_2 is a current-limiting resistor and also serves to drop the plate potential below the ionization potential soon after conduction is initiated. It is clear that the condenser C_2 is charged during a portion of each cycle and then is discharged suddenly when the tube conducts. This discharge of C_2 through the primary of the spark coil P induces a large voltage in its secondary. The sparks obtained were fairly long (1.5 in.), attesting the abruptness of discharge.

A cathode-ray oscillograph affords a convenient and informative means of adjusting the circuit components. The voltage drop across the fuse F was put on the vertical plates, and a 60-c sec^{-1} sweep on the horizontal plates. The oscillogram was characterized by a straight horizontal line interrupted at one or more points by a sharp vertical displacement of large amplitude, followed by a small oscillatory discharge of peculiar wave form. The oscillatory discharge was ignored in making adjustments.

In general, the values of C_1 and C_2 were adjusted to get a single, steep, and large vertical displacement. Delaying the initial discharge by proper phasing with C_1 and increasing

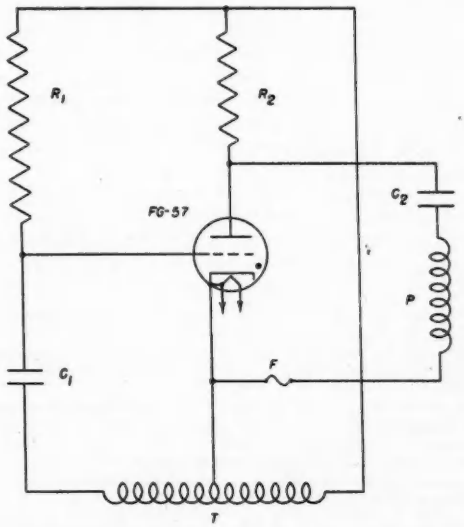

FIG. 1. R_1, 5 megohms (1 w); R_2, 50 ohms (20 w); C_1, 0.001 μf; C_2, 2 μf; P, Ford spark coil primary; T, transformer (Stancor P-6165) secondary (115 v, 60 c sec^{-1} in primary); F, fuse.

the time constant of R_2C_2 (increasing both of them) reduced the number of discharges in each cycle to a single one.

An 884 tube was tried in place of the FG-57, and two differences were noted: first, the oscillogram was characterized by a few vertical displacements of decreasing heights, the oscillatory discharge being absent; second, the 884 tube gave long sparks, but they were not "hot" enough to make large spots on the coated paper used in the free-fall apparatus. Hotter sparks could be obtained by increasing the size of C_2, but there was a slight decrease in accuracy of timing.

The accuracy of timing was judged by the consistancy in values of g obtained with the free-fall apparatus. In that experiment $g=(d_2-d_1)/t^2$, where d_1 and d_2 are successive distances traversed in equal, consecutive time intervals t. The difference which appears in the numerator should be constant along the path of fall. Distances for three sparks ($t=1/20$ sec) were measured and yielded an average deviation from the mean of less than 1 percent, and a maximum deviation from the mean of 2 percent. If all the variation is attributed to the timing of the spark, the error in t is 1 percent of 1/20 sec, or 0.0005 sec.

The circuit is interesting in that it is simple and flexible. Variation in frequency, for example, may be obtained by using an oscillator input into the transformer T. Particularly interesting is the fact that the spark occurs on the "make" of a circuit rather than on the usual "break."

Misuse of the Names of Physical Units

SOME curious practices concerned with units of measurement and their names prevail in some parts of applied physics and, to a certain extent, also in physics proper. Several of the examples that will be mentioned here were turned up in the course of a study now in progress of suitable symbols (abbreviations) for physical units. Most of them, however, are well known and are included in this account merely to make it somewhat more complete.

Names of quantities that incorporate names of units as root words.—Commercial and everyday speech is replete with such expressions as mileage, footage, poundage, tonnage, wattage, voltage and candlepower. As nontechnical words they have the advantage of being more concrete and often more meaningful than are the corresponding physical terms, such as distance, weight and power. As technical terms they are obviously poor, yet some of them occur frequently in physical literature.

"Voltage" is a handy term. Yet it may be ambiguous when used indiscriminately for potential difference, emf and potential. Also, it seems queer to find a particular "voltage" expressed in ergs per statcoulomb or even in microvolts. It is like expressing mileage in meters or feet.

"Candlepower" is faulty on several counts. Sometimes it is used as a substitute for the accepted term, *luminous intensity*; then it is misleading, for luminous intensity is not power, but is luminous flux per unit solid angle. Other times it is used in place of *candle*, the name of the unit of luminous intensity. It is used in both of these senses in an expression of the type, "The candlepower is 32 cp."

Use of unit names to denote quantities.—The practice of naming a quantity after its most common unit is widespread, not only in popular accounts but in many school science textbooks. It is indefensible in all respects, but especially because it encourages sloppy thinking and misconceptions. The following quotations are fairly typical: "Engines develop horsepower by . . ."; "A fuel high in calories . . ."; "An ampere flowing through an ohm produces enough calories to . . ."; "High power factor means that most of one's amperes are doing work and not being wattless." Thus is science brought to the people.

Confusion between the attributes of a quantity and those of its units.—It is not uncommon to find a quality ascribed to a unit of measurement when actually it should be associated with the physical quantity. Common examples are "effective (or rms, or virtual) ampere (or volt)" and "wattless ampere." One may correctly speak of the effective value of a periodic current or, more simply, of the effective current—but not of a current expressed in "effective amperes." Another common example is the expression "pounds per square inch absolute," often abbreviated "psia" by engineers. It is the pressure measurement, not the unit, that is absolute; thus one may correctly write $P_a=15$ lb/in.^{2}, but *not* $P=15$ psia.

M. W. Zemansky has pointed out to us that other widely used expressions falling in this category are "air horsepower," "brake horsepower," "indicated horsepower" and "shaft horsepower."[1] In all four cases the unit is the same—the horsepower. "Brake," for instance, should modify "power"; thus, $P_b=50$ hp, *not* $P=50$ bhp.

In dealing with alternating-current circuits in general, it is found useful to distinguish between active power, reactive power, apparent power, vector power, distortion power, fictitious power, nonreactive power, and mesh power.[2] For all eight of these quantities, the unit of measurement is the same—the *watt* in the practical and mks systems; the *international watt* in the international system. Yet it is common practice to assign eight different names to this unit, one for each quantity; they are, respectively, watt, var, volt-ampere (written with a hyphen), vector volt-ampere, distortion volt-ampere, fictitious volt-ampere, nonreactive volt-ampere, and mesh volt-ampere.[3] Surely no one today would propose that three different names be assigned to the units of impedance, reactance and resistance.

To express the rating of a generator or motor in terms of "kilovolt-amperes," or "kva," is admittedly a concise way of indicating that it is the so-called apparent power that is specified. But that such peculiar terminology can promote foggy thinking is evident from a statement in one textbook: "A kilowatt is the product of a kilovolt-ampere and the power factor."

No amount of discussion is likely to change some of the practices mentioned here, especially when they are firmly established in applied fields and are not a source of inconvenience to highly experienced workers. But something can be done to help students get clear ideas about such terminology at the time when they first encounter it.—D. R.

[1] In *Abbreviations for scientific and engineering terms*, ASA Z10.1—1941 (American Standards Association) these expressions are given the abbreviations "airhp," "bhp," "ihp" and "shp," respectively.

[2] These terms are those recommended and defined in *American Standard definitions of electrical terms*, ASA C42—1941 (American Institute of Electrical Engineers).

[3] See reference 2. The name "var" for the unit of reactive power was adopted at the Stockholm meeting of the International Electrotechnical Commission in 1930.

RECENT MEETINGS

Proceedings of the American Association of Physics Teachers

The St. Louis Meeting, June 20 and 21, 1946

THE American Association of Physics Teachers met jointly with the Society for the Promotion of Engineering Education at St. Louis, Missouri, June 20 and 21, 1946. The afternoon session of the first day, held jointly with the Division of Engineering Mechanics of the SPEE, was concerned with cooperation between departments of physics and mechanics in engineering colleges. The four invited speakers were: R. Z. WILLIAMS, *Missouri School of Mines and Metallurgy;* W. H. MICHENER, *Carnegie Institute of Technology;* R. J. SCHULMEHL, *University of Notre Dame;* J. G. POTTER, *A. and M. College of Texas.*

At the evening session on the same day the following papers were presented: "The elimination of boundaries between mathematics, chemistry and physics," HOMER L. DODGE, *Norwich University;* "Physics courses in the curricula of the technical institutes," MARSH W. WHITE, *Pennsylvania State College;* "Report of committee on curricula in engineering physics," C. E. BENNETT, *University of Maine;* "Physics courses of selected engineering schools," EARL W. THOMSON, *U. S. Naval Academy.* Two contributed papers were also presented: "Interference transmission filters," ROBLEY C. WILLIAMS and L. N. HADLEY, *University of Michigan,* and HENRY M. O'BRYAN, *Baird Associates;* "Experiments and experiences in increasing the efficiency of instruction and learning," G. P. BREWINGTON, *Lawrence Institute of Technology.*

A noon luncheon on the second day of the meeting was addressed by ARTHUR H. COMPTON, *Washington University,* who spoke on "Cultural *versus* practical aspects of physics."

The final session, held in the evening of the second day, was addressed by three invited speakers who discussed undergraduate curricula and textbooks. The titles and speakers were: "From shallow to deep water in physics," R. M. SUTTON, *Haverford College;* "Revision of the junior and senior undergraduate curriculum at Washington University," A. L. HUGHES, *Washington University;* "The contents of a curriculum for the Bachelor's degree," JOSEPH H. HOWEY, *Georgia School of Technology.*

In addition to these sessions, which were held jointly with the Physics Division of SPEE, there were a number of general sessions of SPEE to which members of the Association were welcome.

Attendance

Fifty-five persons registered as attending sessions of the Association. The following members registered:

W. D. Bemmels, Ottawa University; C. E. Bennett, University of Maine; G. P. Brewington, Lawrence Institute of Technology; W. S. Burton, George School; A. H. Compton, Washington University; P. S. Delaup, Southwestern Louisiana Institute; H. L. Dodge, Norwich University; W. H. Eller, State Teachers College, Macomb, Illinois; Sister M. Germaine Fogarty, Webster College; R. C. Gibbs, Cornell University; W. P. Gilbert, Lawrence College; J. H. Howey, Georgia School of Technology; A. L. Hughes, Washington University; E. Hutchisson, Case School of Applied Science; Mother Marie Kernaghan, Maryville College; P. Kirkpatrick, Stanford University; A. A. Knowlton, Reed College; W. H. Michener, Carnegie Institute of Technology; G. E. Owen, Antioch College; W. M. Pierce, Illinois Wesleyan University; E. R. Pinkston, U. S. Naval Academy; J. G. Potter, Texas A. & M. College; W. H. Ross, Massachusetts State College; M. D. Test, Naval Ordnance Laboratory; E. W. Thomson, U. S. Naval Academy; M. W. White, Pennsylvania State College; K. L. Yudowitch, University of Missouri.

PAUL KIRKPATRICK,
Vice President

Western Pennsylvania Section

THE regular spring meeting of the Western Pennsylvania Section of the American Association of Physics Teachers was held on May 11, 1946, at Seton Hill College, Greensburg, Pennsylvania. Some 50 members and guests were in attendance. The following papers were presented:

Report on the annual meeting of the Association. W. C. KELLY, *University of Pittsburgh.*

Stable, unstable and neutral equilibrium. V. HUTCHISON AND H. HILL, *Washington and Jefferson College.*

Present-day curricula in high school science. W. L. WIEGMAN, *South Vocational High School, Pittsburgh.*

Demonstration with a pressure-gage tester. B. L. BRINKER AND A. P. BRINKER, *St. Vincent College.*

Criticism of the Cooperative Physics Tests. O. BLACKWOOD, *University of Pittsburgh.*

At the business meeting Professor O. Blackwood moved the following resolution: "The Association notes with regret that in several Pittsburgh high schools little or no physics laboratory work is done by students. We respectfully suggest that administrative officers take measures to correct this defect in the teaching of physics. The Association gladly offers its services in finding ways to remedy the situation." This resolution was carried unanimously, and the secretary was instructed to communicate it to the proper authorities. Dr. Earl A. Dimmick, the Superintendent of the Pittsburgh Public Schools, has invited the Association to send a committee to confer with the officer in charge of secondary schools.

CHAS. WILLIAMSON,
Secretary

NECROLOGY

Peter Irving Wold, 1881–1945

PROFESSOR WOLD was born in South Dakota. He received the B.S. and the E.E. degrees from the University of Oregon in 1901 and 1903, and the Ph.D. degree from Cornell University in 1915. He came to Union College as head of the department of physics in 1920, after a wide experience in teaching—instructor, Oregon, 1900–03, and Cornell, 1905–08; professor, American Indemnity College, Peking, China, 1911–14; Andrew White Fellow, Cornell, 1915—as well as in applied physics. He had served as examiner of patents in the U. S. Patent Office from 1903 to 1905 and from 1908 to 1910; had been adviser on patent matters to the U. S. Signal Corps in 1910; and was physicist and assistant to the Chief Engineer of the Western Electric Company from 1915 to 1920.

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To Union College PROFESSOR WOLD brought a breadth of outlook on physics, both as a science and as a profession, that led to a vigorous growth of physics on the campus. His first concern was to bring the teaching of physics up to date. He insisted on facilities to meet modern demands, rather than the demands of the generation before. The new laboratory, built in 1926, and the reconstruction of the old laboratory, which is in progress now, bear witness to his efforts; and so does the scope of the physics curriculum that he organized. He realized early the importance of electronics, and in 1920 introduced one of the first under-graduate courses in electronics to be given in this country.

In the classroom he was clear, informal, and always well prepared. He derived great satisfaction from his teaching and from his work with the students; and so did they, especially because of his personal interest in them. Of all the students, he perhaps liked teaching freshmen best; and his revision of Kimball's text permitted some of his ideas on the presentation of introductory physics to spread far outside his own classroom. His demonstration lectures, which he loved to give, had always a freshness that delighted his audiences.

PROFESSOR WOLD'S steady research interest centered on electron tubes and nonlinear circuits, a subject to which he made several important contributions. He had also devoted a considerable time to the Hall effect, to a long path optical interferometer, and to the nature of the red-shift of nebular light. He had been consultant to the General Electric Company, and spent many summers with the American Telephone and Telegraph Company. In 1923–24 he was visiting professor of science in China for the China Medical Board of the Rockefeller Foundation.

During the second world war, PROFESSOR WOLD spent the year 1940–41 at Pearl Harbor as consultant for the U. S. Navy. In 1943 he was liaison officer between the U. S. Navy and the Radiation Laboratory at the Massachusetts Institute of Technology. Presently he became associated with a project of the Office of Scientific Research and Development, while at the same time conducting the affairs of the physics department at Union.

PROFESSOR WOLD was a Fellow of the American Physical Society and was one of the moving spirits of its New York Section. He was a member of the American Association of Physics Teachers and of several other scientific and professional organizations. He had been associate editor of the *Review of Scientific Instruments* and *American Journal of Physics*, and member of committees of the National Research Council. At Union College, where his advice was widely sought, he had been Chairman of the Division of Science and member of the Faculty Council.

He was in vigorous health and very active throughout his life, and therefore his death, on June 17, 1945, was all the more unexpected. He is survived by his wife, Mary Helen Helff Wold, and by two sons and a daughter.

HARRISON C. COFFIN
VLADIMIR ROJANSKY
JOHN BELLAMY TAYLOR